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SOIL AND WATER MANAGEMENT SYSTEMS FOR SLOPING LAND

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PREFACE

Widespread hunger in many parts of the world, coupled with an increasing number of people, dramatizes the need for increased food production. Concern for improvement of the quality of the environment raises questions about the effect of accelerated agricultural production on the ecology.

Much of the agriculture of the Southeast is based on clean-tilled crops grown on sloping land. Other land is in sod crops like coastal bermudagrass, tall fescue, and sericea lespedeza. These crops are grown on soils that are relatively infertile, highly erodible, low in organic matter, and easily compacted by rainfall and machine traffic. These soils respond well, however, to good management practices, including adequate levels of plant nutrients and cropping systems that restore soil organic matter and soil structure and reduce machine traffic.

Rains on clean-tilled soil cause high rates of runoff and soil losses. Rains of large volume and low intensity cause deep percolation that leaches plant nutrients from the soil. High temperatures most of the year cause rapid depletion of soil organic matter. These conditions, when uncontrolled, lead to environmental deterioration by concentrations of plant nutrients, sediments, and other pollutants in drainage water. A long-range result is loss in the productive capacity of the soil.

Cropping systems are needed to replenish soil organic matter, to maintain a high infiltration rate or low overland flow rate in order to reduce surface runoff and prevent soil erosion, to prevent leaching of plant nutrients from the soil, to restore soil fertility, and to maintain good soil structure. Studies were conducted at the Southern Piedmont Conservation Research Center to fulfill those needs.

This publication consolidates previously unpublished data with results published in technical journals since 1955. These studies included cropping systems containing various sequences of sod crops with row crops, fertility treatments, runoff and soil-loss measurements, and other practices designed to control runoff and erosion, prevent leaching of plant nutrients, maintain soil organic matter and good soil structure, produce acceptable yields, and give satisfactory environmental protection.

These data are useful in assessing the environmental hazard from current agricultural practices. This report also shows how cropping and fertility treatments may be combined with other production practices to give the desired environmental control practices.

Studies of a similar nature prior to 1955 were published in U.S. Department of Agriculture Technical Bulletin 1281 and in technical journals.

ACKNOWLEDGMENTS

Much of the data reported here was collected by William E. Adams, soil scientist. He died in 1970 before he could publish the results of many of the studies he conducted during the last 10 years of his tenure (1942–70) at the Southern Piedmont Conservation Research Center. His foresight, leadership, and contribution to the accomplishments of this center are gratefully acknowledged.

Royal N. Dawson, agricultural research technician, worked with W. E. Adams and made many contributions to the success of these studies.

Numerous other center personnel contributed to these studies, and their assistance is acknowledged with grateful appreciation.

Staff members of the University of Georgia College of Agriculture Experiment Stations cooperated in these studies. Special note is given to the following members of the agronomy department: Harold D. Morris, for contributions relating to soil fertility and statistical procedures; Joel E. Giddens, for contributions relating to microbiology; E. R. Beaty, for contributions relating to crop varieties and plant management; and R. A. McCreery, for contributions relating to soil physical problems.

This paper contains the results of research only. Mention of pesticides does not constitute a recommendation for use, nor does it imply that the pesticides are registered under the Federal Insecticide, Fungicide, and Rodenticide Act as amended. The use of trade names in this publication does not constitute a guarantee, warranty, or endorsement of the products by the U.S. Department of Agriculture.

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SOIL AND WATER MANAGEMENT SYSTEMS FOR SLOPING LAND

By John R. Carreker, S. R. Wilkinson, A. P. Barnett, and J. E. Box[1]

ABSTRACT

This publication summarizes 20 years of research on the effects of soil and water management systems on the productivity of the soil and soil erosion losses in the southern Piedmont physiographic region. Research investigations conducted included runoff and erosion studies, crop rotation studies, forage fertilization, liming and irrigation studies as well as studies of no-till corn production in live and killed grass sods. These findings have formed a basis for recommended conservation treatments of southern Piedmont land. Several conclusions are drawn from the 20 years of research. Sod crops improve soil productivity for row crops such as corn. Nitrogen fixed from legume cover crops such as vetch, rye, and alfalfa gave yield responses comparable, or superior, to yields obtained from 80 to 120 lb nitrogen per acre. Tall fescue is effective in nitrogen conservation. Cropping systems that include sod crops in sequence with row crops increase crop yields, increase efficiency of water and fertilizer use, reduce water and soil loss from the land, and provide environmental benefits through smaller losses of sediment and agricultural chemicals from the land. Beneficial effects of sod crops on runoff and soil loss on sloping land extend through the first row crop year following the sod. No-till corn in fescue sod produces excellent yields when nutrient and water requirements are met, and no-till planting in fescue has wide adaptation for the sloping lands of the southern Piedmont. Coastal bermudagrass is superior to common bermudagrass for forage production when its lime and fertilizer requirements are satisfied. Crimson clover overseeded on bermudagrass extends the forage production period and supplies additional forage (clover) yield similar to that obtained with an additional 40 to 80 lb nitrogen per acre applied to coastal bermudagrass. **KEYWORDS: conservation cropping, crop rotation, *Cynodon dactylon,* fertilizers, *Festuca arundinacea,* irrigation, *Medicago sativa,* no-till crop rotation, *Paspalum notatum,* roots, runoff, soil erosion, southern Piedmont, *Trifolium incarnatum, Zea mays.***

INTRODUCTION

The Southern Piedmont

LAND RESOURCES.—The southern Piedmont covers an area of about 59,000 square miles from Virginia to east-central Alabama and lies between the Blue Ridge Mountains to the northwest and the southern Coastal Plain to the southeast. Elevations range from 300 feet along the southeastern edge to about 1,000 feet above mean sea level adjacent to the mountains. This broad plateau is dissected by many streams. The topography is gently rolling, with gentle to moderate slopes on the ridge tops and steeper

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slopes near the streams. Valleys are narrow with little alluvial soil. Soils are deeply weathered from underlying schists, gneisses, and granites, with some areas of basic crystalline rocks and others of sandstones and shales. The Red-Yellow Podzolic soils are dominant throughout. The major series, Cecil, is, under the current soil-classification system, in the Typic Hapludults subgroup and the clayey, kaolinitic, thermic family. Textures range from sandy loam in the topsoil to sandy clay loam or clay in the subsoil. The heavier textures prevail in the surface, where erosion has removed the original topsoil. The Davidson series, typical of the soils derived from basic crystalline rocks, is in the Rhodic Paleudults subgroup, clayey, kaolinitic, thermic family. Textures are usually clay loam to clay. From an agricultural standpoint, other land resource areas related to the southern Piedmont include the southern Coastal Plain, the southern Appalachian Valley and Ridge, and Sand Mountain.

The southern Coastal Plain covers 145,300 square miles from North Carolina to Texas, lying inland about 50 miles from and parallel to the coasts of the Atlantic Ocean and the Gulf of Mexico. This gently to strongly sloping plain is underlain by unconsolidated sands, silts, and clays. The Red-Yellow Podzolic soils are dominant throughout. Three main soil series, Ruston, Norfolk, and Orangeburg, are classified in the Typic Paleudults subgroup and the fine-loamy, siliceous, thermic family. Three Reddish-Brown Lateritic soils, Greenville, Nacogdoches, and Red Bay, are classed in the Rhodic Paleudults subgroup, with the first two in the clayey, kaolinitic, thermic family and the third in the fine-loamy, siliceous, thermic family.

The southern Appalachian Valley and Ridge covers 28,600 square miles from Virginia to Alabama, lying between the Blue Ridge and Cumberland Mountains. Valleys trending northeast to southwest are underlain by limestones and shales and are separated by mountains underlain by sandstones and shales. The topography is undulating to strongly rolling in the valleys and steep on the ridges and mountains. Soil classifications vary widely. Red-Yellow Podzolic soils are dominant in the valleys, with Fullerton and Dewey, two series in the Typic Paleudults subgroup and the clayey, kaolinitic, thermic family. The Colbert series is in the Vertic Hapludalphs subgroup and very-fine, montmorillonitic, thermic family. Decatur, a Reddish-Brown Lateritic soil, is in the Rhodic Paleudults subgroup and the clayey, kaolinitic, thermic family. Another Reddish-Brown Lateritic series, Tellico, is in the Typic Rhodudults subgroup and the clayey, oxidic, thermic family.

Sand Mountain, covering 8,700 square miles in northeast Albama, rises abruptly west of a limestone valley. The sandstone plateau on top with an elevation of 1,000 feet has an undulating to rolling topography that is deeply dissected and steep along the edges. The dominant Red-Yellow Podozolic soils include mainly the Hartsells and Albertville series. Both series are in the Typic Hapludults subgroup. Hartsells represents the fine-loamy, siliceous, thermic family, and the Albertville series is in the clayey, mixed, thermic family.[2]

AGRICULTURE.—Most of the land in the southern Piedmont and related areas is in farms, a small amount is federally owned, and urban areas are a relatively small percentage of the total. Farms generally are small, although the recent trend in size is upward, with a decrease in the number of farms. Traditionally, this has been a cash-crop area. Cotton and corn were the major crops, with peanuts and bright-leaf tobacco also being important in the southern Coastal Plain and burley tobacco in the Tennessee and Kentucky portions of the Appalachian Valley and Ridge. A trend toward fewer row crops and more forages and woodlands that began in the 1940's caused a large reduction in acreage of row crops in the southern Piedmont and the Appalachian Valley and Ridge, and a lesser reduction in the southern Coastal Plain and the Sand Mountain areas. The acreage of soybeans increased rapidly during the 1960's and early 1970's, particularly in the southern Coastal Plain. With these shifts in cropping, a large increase in livestock, particularly beef cattle, and poultry caused an extreme deficit of grain production in these areas. Current agricultural trends indicate that the

[2] See the reference *6* in "Literature Cited" for a more complete discussion of land resource areas. The soil descriptions were obtained from the Soil Classification System, Placement of Series, South Region, January 1970, distributed by U.S. Department of Agriculture, Soil Conservation Service, South Regional Technical Service Center, Ft. Worth, Tex. 76110.

acreage of soybeans and feed grains will increase.

CLIMATE.—The climate throughout these areas is mild and conducive to sustained agricultural production. There is some variation within each area and from area to area, as shown by the following average annual data:

Land resource area	*Rainfall* (inches)	*Temperature* (°F)	*Frost-free days*
Southern Piedmont	45–55	57–65	200–250
Southern Coastal Plain	40–60	60–68	200–280
Southern Appalachian Valley and Ridge	35–55	50–60	160–220
Sand Mountain	54	60–62	200–210

The combination of these elements—a large number of frost-free days coupled with mild temperatures and favorable rainfall—makes possible a wide range of crops. However, these favorable factors also create some problems. Much of the rainfall occurs in high-intensity storms with rates in excess of the infiltration capacity of the soil. The resulting runoff causes severe erosion on sloping fields in clean-tilled crops. Many of the sandy soils have a low water-holding capacity. The runoff water often is needed to replenish the soil-water supply in the root zone of the crop. The mild temperature promotes activity by soil microbes throughout the year, restricting a buildup in soil organic matter and permitting the leaching of plant nutrients by excess rains in the dormant season of a crop. Distribution of rainfall is often erratic in both time and space. Although the average annual rainfall is excellent, periods of 20 days without rain are common, and periods of 30 days without rain occur occasionally. Crop production is reduced when these rainless periods coincide with the period of crop need.

CONSERVATION NEEDS.—Most of the cropped land in the southern Piedmont, southern Appalachian Valley and Ridge, and Sand Mountain is in soil capability classes II and III. Little class I land is present in these areas, and the class IV land formerly in cultivated crops is now in perennial grasses or trees. A higher proportion of cultivated crops occurs on class I and class II land, with some also on class III, in the southern Coastal Plain. Conservation needs are similar on these land classes regardless of the land resource area. Oconee County, Ga., may be considered typical of the southern Piedmont and representative of the other areas. Data compiled by the Georgia Soil and Water Conservation Needs Inventory[3] in 1962 projected the conservation needs in Oconee County by 1975 to be:

Land	*1,000 acres*				
	Land capability class				*Total acreage*
	I	II	III	IV	
Total cropland	0.5	15.7	6.5	1.5	24.2
Cropland with no problem					.5
Cropland on which the dominant problem is erosion					22.3
Cropland on which the dominant problem is excess water					1.3
Cropland on which the dominant problem is unfavorable soil conditions					0
Total pastureland	.3	3.3	6.2	6.3	16.7
Pastureland needing reestablishment of vegetation					6.8
Pastureland needing improvement of vegetative cover					4.2
Pastureland needing protection from erosion					2.0
Pastureland needing water conservation					1.8

These data show that crops are grown mainly on land classes II and III, and pastures on III and IV. The dominant conservation needs are erosion control on cropland and reestablishment or improvement of vegetative cover on pastures.

Southern Piedmont Conservation Research Center

Soil and water conservation research was initiated at the Southern Piedmont Conservation Research Center (SPCRC), Watkinsville, Oconee County, Ga., in 1938. The center contains 981 acres of typically sloping Piedmont land with primarily the Cecil soil series. The surface soil texture is mainly sandy loam, with some areas of loamy sand and others of sandy clay loam. This sandy clay loam reflects excessive erosion under the earlier cropping treatments used on the various slopes. Early

[3] Mimeographed publication by the Georgia Soil and Water Conservation Needs Committee, sponsored by the Georgia State Soil Conservation Committee, May 1962.

studies at the center during 1940–55 were designed to determine the rates, amounts, and factors causing runoff and soil losses, and to develop cropping systems for their control. Hendrickson et al. (*14*)[4] reported that these studies, based mainly on cotton, corn, small grains, and annual lespedeza, with some sericea lespedeza and kudzu, showed that erosion on land in row crops increased with land slope and was greatest during the summer when most of the high-intensity rainstorms occurred, and that close-growing crops gave excellent erosion control, even on steep slopes. Crop yields were shown to be proportional to the depth of topsoil remaining on the land.

New studies were initiated about 1955 to determine the feasibility of growing perennial sods and rotations of row crops with these sods under Piedmont conditions. Determinations were made of the responses from these crop and crop sequences to fertility levels, water levels (irrigation), tillage practices, and harvest schedules. Runoff and soil losses were measured, and erodibility of other soils was determined. Most studies were located on field plots small enough for replication of treatments and large enough for use of regular farm machinery. Normal tillage and other production practices were employed, except where some other specific treatment was required. Slopes and soils were those existing naturally on the sites. Results from those studies conducted at SPCRC since 1955 are reported in this publication.

Seven types of studies were conducted during the period of record in this report: (1) cropping systems using row crops and sod crops, (2) rainfall, runoff, and soil losses, (3) bermudagrass for forage, (4) effect of tall fescue on corn yields, (5) corn after sericea lespedeza, (6) interseeding other crops with coastal bermudagrass, and (7) corn in tall fescue.

CROPPING SYSTEMS USING ROW CROPS AND SOD CROPS

TREATMENTS.—Twelve cropping systems were established in 1955 on an area of Cecil soil, class II land with 1- to 3-percent slope. Rescuegrass (*Bromus catharticus* Vahl.) and crimson clover (*Trifolium incarnatum* L.) had been grown on that site with only seed harvested and all residues returned to the land for the previous 5 years. These 12 cropping systems were: (1) corn (*Zea mays* L.) continuously, (2) corn continuously with vetch (*Vicia villosa* Roth) green manure, (3) corn continuously with rye (*Secale cereale* L.) green manure, (4) 4-year rotation of alfalfa (*Medicago sativa* L., 'Kansas Common' variety) 2 years, then corn 2 years, (5) 4-year rotation of 2 years tall fescue (*Festuca arundinacea* Schreb., 'Kentucky 31' variety), then corn 2 years, (6) 4-year rotation of 3 years alfalfa, then corn 1 year, (7) 4-year rotation of 3 years tall fescue, then corn 1 year, (8) 4-year rotation of 3 years coastal bermudagrass [*Cynodon dactylon* (L.) Pers.], then corn 1 year, (9) alfalfa continuously, (10) tall fescue and crimson clover continuously, (11) coastal bermudagrass and crimson clover continuously, and (12) Pensacola bahiagrass (*Paspalum notatum* Flügge) continuously.

Cropping systems 1, 2, and 3 were divided into subsystems A, with the cornstalks left on the land, and B, with the stalks removed after grain harvest. These subsystems were considered as separate treatments in the experimental design, which was whole plots for cropping treatments and split plots for four levels of nitrogen to the corn. There were two replicates for each treatment. Each crop was represented each year in each cropping system after the 4-year rotations became fully established. The first and second years of corn in the rotation systems 4 and 5 were treated as separate systems also in the statistical analysis of yields.

All plots were limed in 1955 to pH 6.5, with the lime being plowed into the soil. Subsequent applications of lime were made on an individual plot basis according to soil test to maintain this pH level.

An initial application of 360 lb P_2O_5/acre, 360 lb K_2O/acre, and 20 lb borax/acre was made to eliminate deficiencies of these minerals. Annual fertilizer applications included 100 lb P_2O_5/acre and 200 lb K_2O/acre to all plots, plus 20 lb borax/acre to alfalfa. Half of this P and K was applied ahead of plowing and the remainder in the row when corn was planted in all treatments except 2B and 3B. Half the P and K was applied to the vetch and

[4] Italic numbers in parentheses refer to items in "Literature Cited" preceding the appendix.

rye at planting in the fall, one-fourth was broadcast ahead of turning these crops in the spring, and one-fourth was applied in the corn row at planting. All P and K was broadcast in split applications in spring and fall on the alfalfa and the three grasses.

Nitrogen was applied to all corn at rates of 0, 40, 80, and 240 lb/acre in the four split plots. The rate of 240 lb/acre was reduced to 160 lb/acre in 1961 because the higher rate caused detrimental effects on the corn during dry periods. Except where no N was applied, the N application was 20 lb/acre applied in the row at planting and the remainder as a side dressing about 40 days after planting. The rye, tall fescue, and coastal bermudagrass in rotation each received 80 lb N/acre total, in split applications. Vetch and alfalfa did not receive N. The perennial grass sods of fescue, bermudagrass, and bahiagrass received annual applications of 80 lb N/acre through 1959. Split-plot treatments of 0, 80, 160, and 320 lb N/acre were initiated in 1960. White clover (*Trifolium repens* L.) was seeded with the grasses through 1959, and crimson clover was used thereafter. 'Kentucky 31' fescue was seeded to establish each new stand, but the bermudagrass volunteered from live plants in the corn.

The sod or cornstalk land was turnplowed and harrowed to prepare a seedbed for the corn each spring. Corn was planted in rows 42 inches apart for a stand of 10,000 plants per acre. Locally adapted hybrids were grown. Normal planting and cultivation equipment were used. Corn yields were taken from 25 feet of the inside four rows in each six-row, split plot, and grain weights were corrected to the 15-percent moisture level. Forage crops were harvested from each split plot, dried at 65° C, and the yield recorded as ovendry weights.

Determinations of soil physical properties were begun on duplicate plots of these treatments in 1962, the eighth year the cropping systems had been in effect. Textural analyses were by the hydrometer method (*10*). Aggregate stability was determined by the Yoder (*23*) wet-sieve method from samples taken in the spring of 1962 and 1963 and the fall of 1964. Bulk density was determined with 3-inch cores of undisturbed soil. Pore-size distribution was computed from the drainage at various tensions with these undisturbed cores on a tension table and pressure plates. Moisture-desorption curves were developed from disturbed samples run in the pressure plate and pressure-membrane apparatus. Crust strength was measured onsite with a hand penetrometer at nine locations in the row and in the middle under corn for certain of the cropping treatments. Infiltration rates were measured with the Bertrand and Parr (*9*) sprinkling infiltrometer. Rainfall rates were obtained from a recording rain gage and amounts from a National Weather Service standard gage mounted within the plot.

Infiltrated rainfall that caused the soil-water content to exceed field capacity of the soil was considered as excess soil water lost as deep drainage. That portion of a rain at a rate in excess of the infiltration rate was considered to be lost as runoff. The need for irrigation was computed by the formula

$$I = A + R - R_o - (ET \times D), \qquad (1)$$

where I=irrigation needed, A=available water in the soil=field-capacity—wilting point, R=rainfall, R_o=runoff, ET=daily rate of evapotranspiration, and D=number of days. An irrigation was deemed necessary when the available soil water was depleted by 65 percent.

The rotation systems of alfalfa and corn (treatments 4 and 6) were terminated after the 1961 crop because of poor alfalfa stands. Corn was planted continuously in the following years on these plots to measure the residual effects of alfalfa.

All other cropping systems were terminated after the 1964 crop season for a study of the residual effects of these treatments. Corn was grown for 4 years in succession on those treatments. The grass was retained in the sod-based rotations until the corn followed the normal cycle of 2 or 3 years of grass as in the regular cropping sequence. This gave corn 1, 2, 3, 4, and 5 years after grass, as well as that grown 11 to 14 years in the original continuous corn treatments. Nitrogen was applied to the corn at the usual 0, 40, 80, and 160 lb/acre rates on the split plots.

RESEARCH RESULTS.—(*1*) *Corn yields.*—The sequence of crops in the 4-year rotations occurred for the first time in 1958. Average yields of corn during the 1958 to 1964 7-year period (table 1) varied from 25.5 bu/acre from corn continuously (treatment 1) without N to

TABLE 1.—*Yield of corn by cropping treatment and level of nitrogen application, 1958–64, 7-year average*[1]

[Bushels per acre]

Treatment No.	Cropping treatment	Corn yield at rate of nitrogen applied to corn (lb/acre)			
		0	40	80	[2]160
1A	Corn, with stalks left on land	25.5e	63.4d	75.4de*	76.6d*
1B	Corn, with stalks removed from land	27.1e	68.6d	73.1e*	76.8d*
2A	Corn after vetch green manure, stalks on	84.7a*	85.1abc*	88.7bc*	86.9bcd*
2B	Corn after vetch green manure, stalks off	81.7a*	80.6c*	83.8cd*	84.5cd*
3A	Corn after rye green manure, stalks on	62.7c	88.2abc*	91.5abc*	94.6abc*
3B	Corn after rye green manure, stalks off	60.0c	83.3abc*	83.9cd*	89.1abc*
4A	Corn, 1st year after 2 years of alfalfa	76.4ab	87.1abc*	92.4abc*	91.1abc*
4B	Corn, 2d year after 2 years of alfalfa	61.4c	78.4c*	85.5bc*	85.4bcd*
5A	Corn, 1st year after 2 years of fescue+crimson clover	62.7c	90.9ab*	94.7ab*	92.5abc*
5B	Corn, 2d year after 2 years of fescue+crimson clover	49.0d	82.1abc*	91.3abc*	87.2bcd*
6	Corn after 3 years of alfalfa	78.2ab	91.9a*	95.8ab*	97.6ab*
7	Corn after 3 years of fescue+crimson clover	69.6bc	91.0ab*	99.1a*	100.7a*
8	Corn after 3 years of coastal bermudagrass+ladino clover	65.0c	84.6abc*	88.3bc*	89.9abc*

[1] Values in a column followed by the same letter are not significantly different at the 95% level. Values within a cropping treatment followed by an asterisk are not significantly different at the 95% level.

[2] 240 lb/acre applied 1958–60.

100.7 bu/acre from corn after 3 years of tall fescue plus crimson clover (treatment 7) with 160 lb N/acre. There was no increase in yield from N applied to corn after vetch. The first 40 lb N/acre gave statistically significant increases over no N on all other treatments. Yields from 80 lb N/acre were significantly higher than from 40 lb N/acre only with corn continuously (treatment 1), second corn after tall fescue (treatment 5B), and corn after both coastal bermudagrass and tall fescue 3 years (treatments 7 and 8). There was no significant increase from 160 lb N/acre over 80 lb N/acre on any treatment.

Removal of cornstalks did not affect corn yields at any N level in treatments 1, 2, and 3. Turning the cover crops of vetch, rye, alfalfa, tall fescue+clover, and bermudagrass+clover ahead of the corn gave significant yield increases over no cover crop at all levels of N (treatment 1 versus all other treatments). The yield of the corn without N after the rye and the grasses reflects the effect of the N applied to the rye and grasses and the clover in the grasses ahead of the corn. Vetch and alfalfa gave significant increases over other treatments where no N was applied. Yields of the corn were significantly less the second year than the first year after alfalfa and after tall fescue+clover where no N was applied, but this difference did not occur at other rates of N. Yields were as high following 2 years of sod (treatments 4 and 5) as 3 years of sod (treatments 6 and 7). Grain response at the higher N rates probably was limited by the plant population of only 10,000 plants per acre and the genetic capability of the 'Dixie 82' hybrid used.

No trends in corn yields could be established from the accumulative effects of the cropping treatments because of the wide variation in corn yield from year to year on all treatments.

TABLE 2.—*Yields of forages (ovendry basis) grown in rotation with corn, 1958–64, 7-year average*[1]

Treatment No.	Type of forage	Years of corn ahead of forage	Years of forage after corn	Forage yields (tons per acre)				
				Nitrogen applied to corn (lb/acre)				Average yield[2]
				0	40	80	160	
2A	Vetch green manure	1	1	0.46*	0.50*	0.54*	0.57*	0.52g
2B	do	1	1	.51*	.53*	.52*	.55*	.53g
3A	Rye green manure	1	1	1.21*	1.33*	1.62†	1.73†	1.47f
3B	do	1	1	1.38*	1.42*	1.73†	1.97†	1.63e
5A	Fescue and clover	2	1	1.32*	1.32*	1.36*†	1.49†	1.37f
5B	do	2	2	1.88*	2.03*	2.06*	2.25	2.06c
7A	do	1	1	1.55*	1.56*	1.68*†	1.77†	1.64e
7B	do	1	2	1.87*	2.00*†	2.14†‡	2.19‡	2.05c
7C	do	1	3	1.93*	1.81*	1.94*	1.91*	1.90d
8A	Coastal bermudagrass and clover	1	1	1.93	2.07	2.19*	2.58*	2.19c
8B	do	1	2	2.98*	2.98*	3.06*†	3.23†	3.06
8C	do	1	3	3.25*	3.33*	3.22*	3.37*	3.29a
4A	Alfalfa	2	1	1.90*	1.89*	2.10†	2.05†	1.99
4B	do	2	2	3.33*	3.34*	3.18*	3.26*	3.28
6A	do	1	1	1.68*	1.67*	1.88†	1.89†	1.78
6B	do	1	2	3.13	3.44*	3.29*	3.29*	3.29
6C	do	1	3	3.48*	3.62*	3.52*	3.56*	3.55

[1] Alfalfa yields were for 1958–61, 4-year period. Values within a cropping treatment followed by the same symbol are not significantly different at the 5% level.

[2] Duncan's new multiple-range test; values followed by the same letters are not significantly different at the 5% level.

Rainfall in June and July had more effect on yield from year to year than did cropping treatment (fig. 1 and table A–1).

(*2*) *Forage yields.*—The weight (ovendry basis) of forages grown in rotation with the corn ranged from an average of about 0.5 ton per acre for vetch that was turned for green manure to 3.3 tons per acre for third year coastal bermudagrass+clover hay (table 2). Higher rates of N applied to the corn increased the yields of grasses and alfalfa the first year after corn, but these effects were gone by the third year of the sod crops. Vetch yield was not affected by the N applied to corn. The order of forage production was third coastal>second coastal>first coastal=second fescue>third fescue>first fescue after 1 year of corn>first fescue after 2 years of corn=rye>vetch. Alfalfa yielded slightly less than 2 tons per acre the first year after corn, 3.3 tons per acre the second year, and 3.5 tons per acre the third year. Yields of all crops varied widely from year to year in response to different weather conditions. Since the alfalfa rotations were grown 4 years and the other rotated crops for 7 years, valid comparisons of yields of alfalfa and the other forages cannot be made from the information presented.

These same perennial forages, plus Pensacola

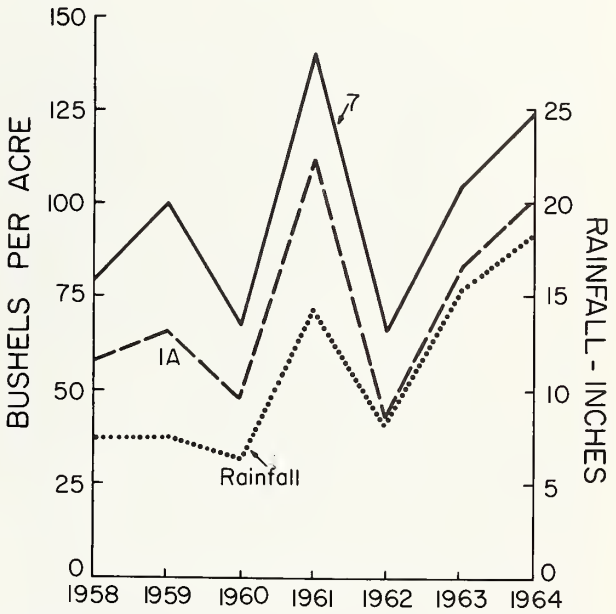

FIGURE 1.—Relation of corn yields to rainfall in June and July by years, for corn continuously (1A) and corn after 3 years of tall fescue (7) with 80 lb nitrogen per acre.

bahiagrass with crimson clover, were grown on companion plots in perennial stands and not rotated with corn. The initial fertilization scheme included an annual rate of 80 lb N/acre to the grasses and no N to alfalfa. Forage yields for the 1958 to 1964, 7-year period with the rate of 80 lb N/acre averaged 3.52, 2.88, 2.86, and 1.64 tons per acre for alfalfa, bahiagrass, bermudagrass, and tall fescue, respectively. Additional N rates of 0, 160, and 320 lb/acre were established on the grasses in 1960. Yields of the bermudagrass were similar to bahiagrass at the 0, 80, and 160 lb N/acre rate, but the bermudagrass yield was higher than the bahiagrass at 320 lb N/acre (fig. 2). Both these grasses yielded higher than the tall fescue at all rates of N. Alfalfa yield, with no N applied, was equal to bermudagrass and bahiagrass with 120 lb N/acre and tall fescue with 300 lb N/acre (fig. 2 and table A–2).

(*3*) *Nematodes.*—Brodie et al. (*11*) showed that the population of several species of ectoparasitic nematodes was affected by the cropping treatment. The species *Practylenchus zeae* grew best in the continuous corn treatments, with counts of the number in 150 cm^3 of soil being 75+ for corn after vetch, 55 for corn alone, and 50 for corn after rye. There were less than 10 of *Trichodorus christiei, Helicotylenchus dihystera,* and *Xiphinema americanum* in any corn after corn treatment, but considerably larger numbers of these 3 species were found where corn followed fescue grass and coastal bermudagrass and under these grasses and alfalfa. These counts showed that alfalfa and the grasses were unfavorable hosts for *P. zeae,* but favorable for *T. christiei,* indicating the ability of different nematode species to adapt to selected hosts. The total count for all species was lowest with coastal bermudagrass, but this reduced count was not reflected in the corn yield following this grass.

(*4*) *Soil physical properties.*—The sandy loam soil on the plots averaged 71, 12, and 17 percent sand, silt, and clay, respectively. Total pore space in the Ap horizon, measured in 1962, ranged from 36 to 41 percent, and averaged 38 percent for all treatments. Large pores drained at 60-cm tension ranged from 49 to 63 percent and averaged 56 percent of the total pore space. Neither cropping treatments nor N levels had any effect on total porosity or pores drained at 60-cm tension. Stability of soil aggregates was affected markedly by cropping treatment (table 3). The percentage of total aggregates and of large aggregates increased as the amount of cover crop increased. The percentage of large aggregates ranged from 8 with corn continuously to 11 with corn after rye green manure and 15 with corn after 3 years of coastal bermudagrass. Total aggregates followed this same order with 22, 31, and 35 percent, respectively, for these same three treatments. Coastal bermudagrass continuously had 44 percent total aggregates.

The unconfined strength of soil crusts decreased as the amount of crop residue was in-

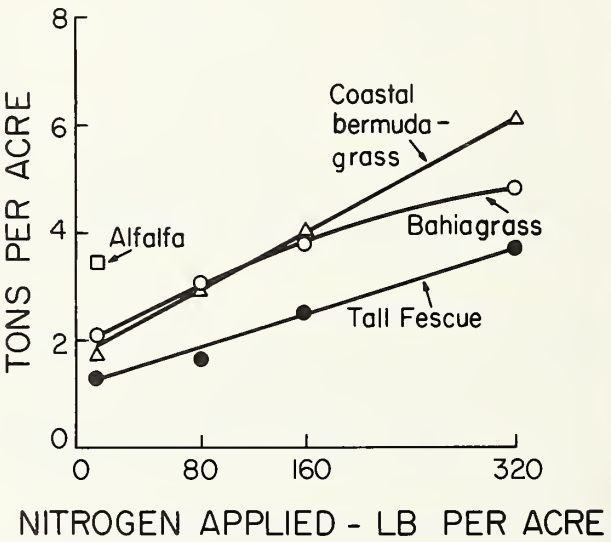

FIGURE 2.—Annual yields of forages with different levels of nitrogen applied to the grasses and clover, 1960–64 average.

TABLE 3.—*Water-stable aggregates by cropping treatment and size of sieve*[1]

[Percent aggregates]

Treatment No.	Sieve mesh number				Total
	10	20	40	60	
1B	8.38cd	4.00d	5.87b	3.57b	21.92c
1A	7.50d	5.22cd	7.84a	3.61b	24.18c
3A	11.84bc	6.40c	7.62a	4.47ab	30.32bc
3B	10.63bc	6.36c	8.51a	5.14a	30.64bc
8	14.62b	7.56bc	8.53a	5.04a	35.75ab
10	20.52a	8.28ab	8.07a	3.89ab	41.31a
11	21.04a	9.79a	9.06a	4.05ab	43.93a

[1] Values in a column followed by the same letter are not significantly different at the 5% level.

creased, but N level had no effect on soil strength. The average values from 18 measurements per treatment were 1.9, 1.2, and 0.7 kg/cm^2 for corn continuously (treatment 1), corn after rye green manure (treatment 3), and corn after 3 years of tall fescue (treatment 7), respectively.

Data from soil samples taken for bulk density and water retention measurements in 1962, 1963, and 1964 showed some effect of treatment on these properties (table 4), but the variability between replications and years was so great that the differences were not statistically significant.

Rate of infiltration was related to cropping treatment and time of year (table 5). The time for runoff to begin after rainfall started was consistently less in the fall than in the spring for all treatments, but there was no consistent pattern of treatment effect between fall and spring on final rates. The terminal rates in the spring were highest with, but not significantly different among, coastal bermudagrass (2.02), alfalfa (1.79), the 4-year rotation of coastal bermudagrass and corn (1.61), the 4-year rotation of fescue grass and corn (1.73), and the corn continuously following rye (1.51). The lowest rate was from corn continuously with the stalks removed from the land (0.90). The terminal rates in the fall were highest and not significantly different on the 4-year corn rotations with coastal bermudagrass (3.38) and fescue grass (3. 43) and the corn continuously with rye green manure (3.34). Rates were least and not different for corn continuously with stalks removed (1.71), the fescue-grass sod (1.48), and the coastal sod (1.26). The change in infiltration rate with time is expressed by the formula

$$Y=a+bX+cX^2, \qquad (2)$$

where Y=infiltration rate, X=time in minutes, and a, b, and c, are constants. The values for the constants, a, b, and c, in table 6, show a reasonably good fit of the data (R^2 values) for most of the eight cropping treatments studied.

(*5*) *Irrigation requirement.*—Rainfall amounts and intensities were combined with the infiltration rates in table 6 to calculate the irrigation requirements of the eight cropping treatments listed in that table. The amount and intensity of each rainstorm from May 1 to

TABLE 4.—*Bulk density, water retained at different tensions, and available water capacity (AWC) of Cecil sandy loam, 0- to 6-inch depth, with eight cropping treatments*

Treatment No.	Replication	Bulk density (g/cm^3)	Water retained (% by vol) at bars tension					AWC (cm/cm)
			⅓	2	4	8	15	
1B	1	1.50	12.45	10.25	8.43	7.07	6.30	0.157
	2	1.65	13.81	11.35	9.65	8.05	6.22	.183
1A	1	1.63	13.43	10.95	8.74	7.16	6.00	.188
	2	1.62	12.15	8.85	6.98	5.83	4.70	.188
3A	1	1.63	17.25	13.89	10.94	9.05	4.11	.333
	2	1.70	16.71	12.68	10.64	8.48	7.19	.241
[1]6	1	1.58	16.76	13.48	11.30	9.07	7.44	.236
	2	1.61	14.01	10.72	8.58	6.99	5.04	.229
[1]8	1	1.43	9.31	7.36	6.03	4.70	4.46	.124
	2	1.65	13.35	10.64	9.42	7.57	6.17	.183
9	1	1.56	13.85	10.45	8.14	7.21	5.80	.206
	2	1.68	12.55	8.84	7.02	5.92	5.49	.180
10	1	1.62	12.26	11.13	9.32	7.55	7.26	.127
	2	1.77	16.71	13.98	10.09	8.80	6.97	.246
11	1	1.51	14.21	13.54	9.68	8.43	7.14	.180
	2	1.72	11.27	9.46	7.57	6.45	3.14	.206

[1] Corn after grass.

TABLE 5.—*Application rate, soil moisture at beginning of test, time for runoff to begin, and infiltration rate at selected time intervals for each cropping treatment in the spring and fall (1962, 1963, and 1964 averages)*

Treatment No.	Application rate (in/h)	Soil moisture[1] (%)	Time for runoff to begin[2] (min)	Infiltration rate (in/h) at selected times in minutes from beginning of rainfall						
				5	10	15	30	45	60	Terminal[3]
				Spring						
1B	4.48	8.6	7.5c	4.48	3.58	2.88	1.29	0.90	...	0.90c
1A	4.18	8.5	7.8c	4.18	3.22	2.35	1.44	[3]1.24	...	1.10bc
3	4.43	9.0	8.5c	4.43	4.19	3.70	2.50	1.78	...	1.51ab
7	4.53	8.1	7.1c	4.53	3.65	3.01	2.03	...	...	1.73a
8	4.63	8.0	9.5c	4.63	4.34	4.08	2.68	2.01	1.61	1.61ab
9	4.56	4.0	9.4c	4.56	4.45	4.28	3.51	2.47	2.05	1.79a
10	4.62	7.7	14.4b	4.62	4.62	4.51	3.85	2.81	1.81	1.48b
11	4.57	8.8	19.0a	4.57	4.57	4.57	3.34	2.62	2.02	2.02a
				Fall						
1B	4.69	7.6	4.0a	4.29	3.40	2.76	1.91	...	...	1.71c
1A	4.64	9.3	4.9a	4.45	4.16	3.80	3.03	2.41	...	2.28b
3	4.69	9.0	4.8a	4.65	4.55	4.40	4.06	3.82	3.49	3.34a
7	4.70	10.0	4.1a	4.49	4.30	4.15	3.93	3.75	3.43	3.43a
8	4.65	10.2	5.6a	4.65	4.41	4.22	3.54	3.41	...	3.38a
9	4.66	4.9	4.0a	4.06	3.42	3.26	2.86	2.54	...	2.29b
10	4.65	6.8	3.5a	4.63	4.58	4.53	4.12	2.71	1.48	1.48c
11	4.62	9.0	6.1a	4.62	4.55	4.48	3.73	2.05	1.36	1.26c

[1] Moisture at start of test, 0- to 6-in soil depth, percentage by weight.
[2] Values followed by the same letter are not significantly different at the 5% level for each season.
[3] Terminal rate at 35 minutes.

TABLE 6.—*Formulas for infiltration rates with time for eight cropping treatments on Cecil sandy loam soil in the spring and fall*

Treatment No.	Cropping treatment	Formula[1]	Correlation coefficient (R^2)
		Spring	
1B	Corn, stalks off	$Y=5.25-0.193X+0.002X^2$	0.786
1A	Corn, stalks on	$Y=5.26-0.230X+0.003X^2$	.740
3A	Corn, rye cover crop	$Y=5.43-0.130X+0.001X^2$	.938
7	Corn after 3 years fescue	$Y=5.16-0.167X+0.002X^2$	.472
8	Corn after 3 years coastal	$Y=5.44-0.115X+0.001X^2$	.626
9	Alfalfa	$Y=5.28-0.072X+0.0003X^2$	.542
10	Fescue and clover	$Y=4.96-0.014X-0.0007X^2$	.776
11	Coastal bermudagrass	$Y=5.42-0.075X+0.0003X^2$	.686
		Fall	
1B	Corn, stalks off	$Y=5.12-0.188X+0.0026X^2$	0.477
1A	Corn, stalks on	$Y=4.84-0.075X+0.0005X^2$	.678
3A	Corn, rye cover crop	$Y=4.72-0.021X+0.0000X^2$	.674
7	Corn after 3 years fescue	$Y=4.64-0.029X+0.0002X^2$	.152
8	Corn after 3 years coastal	$Y=4.96-0.069X+0.0008X^2$	.152
9	Alfalfa	$Y=4.39-0.073X+0.0007X^2$	.566
10	Fescue and clover	$Y=4.58-0.019X-0.0013X^2$	.773
11	Coastal bermudagrass	$Y=5.20-0.053X-0.0002X^2$	.899

[1] Y = infiltration rate in inches per hour; X = time from beginning of rain in minutes.

August 31 during 1962, 1963, and 1964 were tabulated. The portion of each rain where the intensity was greater than the infiltration rate for each treatment, as expressed by the appropriate formula in table 6, was regarded as runoff. That portion of the rain with an intensity equal to or less than the infiltration rate was regarded as being infiltrated. Infiltrated rainfall in excess of the amount needed to restore the soil water to the 2.29-inch available water capacity of the 0- to 24-inch main root zone was treated as lost by deep percolation. The available soil water was depleted by evapotranspiration at daily rates of 0.15, 0.18, 0.16, and 0.14 inches (*17*) for May, June, July, and August, respectively. Irrigation was assumed to be needed when the soil-water balance approached 0.69 inch (one-third of the total available water capacity), and an amount was assumed added to restore the balance to 2.29 inches. The actual rainfall and calculated amounts of runoff, percolation, and water stored in the soil are given by years for four cropping treatments in figure 3. Although rainfall varied from 11.30 inches in 1962 to 24.84 inches in 1964, the water stored in the soil (effective rain), which was the amount available for use by the crops, was nearly constant between years and by crops. As runoff increased as a result of a lower infiltration rate, the loss by deep percolation decreased, causing uniform amounts of water to be stored in the soil available for plant use. This uniformity made the irrigation requirement practically the same for all treatments.

The relationship between corn yield and amount of rain (fig. 4) shows that yield was much more responsive to effective rain than to total rain. Rain in June and July only was used for this graph. The lines shown are for cropping treatments 1B and 7. Determinations of these relationships for treatments 3 and 8 showed that they fell between the lines for treatments 1B and 7.

Corn yields were related inversely to the number of drought days in June and July each year (fig. 5). Drought days were computed by depleting the soil-water content by the evapotranspiration rate each day until no available water was left in the soil. Rains restored the soil water to the extent of the effective rainfall. As with total and effective rainfall, the relationship of drought days to yield for treatments 3 and 8 was within that shown for treatments 1B and 7.

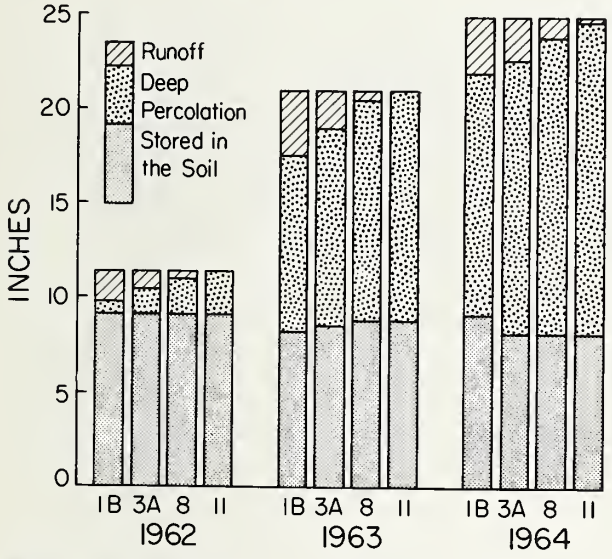

FIGURE 3.—Disposition of rainfall from May 1 to August 31 with cropping treatments of corn (1B), corn and rye (3A), corn after coastal bermudagrass (8), and coastal bermudagrass sod (11).

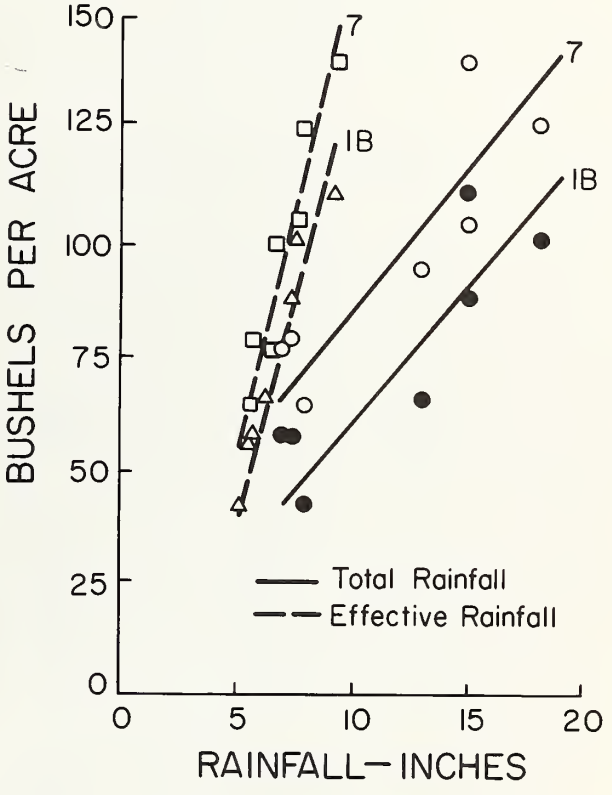

FIGURE 4.—Relation of corn yields to total and effective rainfall in June and July on cropping treatments 1B and 7.

Water lost through deep drainage is no more available to plants than water lost as surface runoff. However, lower rates of runoff, resulting from higher infiltration rates, cause less erosion on sloping land. Also, water passing through the soil profile causes the loss of soluble soil nutrients and lowers the soil pH and fertility level. The water lost through deep drainage might be available later from wells or in downslope water courses supplied from interflow. Thus, the higher infiltration capacities resulting from improved cropping systems could serve a useful purpose by causing water to be stored in the soil for later release and use.

(*6*) *Carbon and nitrogen contents of soil.*—Nitrogen and organic carbon contents of the soil were determined from samples taken from the top 6 inches of soil under each crop in the spring before differential N applications. Nitrogen determination in 1963 and 1964 showed that the percentage of N was about 0.04 with corn continuously and 0.05 to 0.07 for other cropping treatments. There was slightly more N in the soil where 160 lb N/acre was applied than where no N was applied to the corn.

Carbon content was determined under all cropping treatments in 1962, 1963, and 1964, and in the residual-phase corn in 1966 (table 7). The percentage of carbon varied more between years for a given treatment than between most treatments. The carbon was lower in corn continuously than in all other treatments, and

TABLE 7.—*Organic carbon in top 6 inches of soil under different cropping treatments*

Treatment No.	Cropping treatment	Organic carbon (%) at rate of nitrogen applied (lb/acre) in—							
		1962		1963		1964		1966	
		0	160	0	160	0	160	0	160
1A	Corn, stalks on	0.42	0.52	0.45	0.55	0.53	0.63	0.43	0.55
1B	Corn, stalks off	.47	.48	.48	.48	.57	.56	...	...
2A	Vetch green manure, corn, stalks on	.61	.69	.61	.68	.76	.83	.61	.62
2B	Vetch green manure, corn, stalks off	.60	.57	.55	.61	.71	.68	...	...
3A	Rye green manure, corn, stalks on	.59	.76	.59	.75	.81	.91	.67	.74
3B	Rye green manure, corn, stalks off	.63	.71	.62	.72	.80	.91	...	...
4A	1st corn after alfalfa	.72	.65	.66	.68	.73	.70	.62	.62
4B	2d corn after alfalfa	.62	.74	.52	.53	.75	.82	.56	.68
5A	1st tall fescue after corn	.51	.57	.60	.63	.84	.75	...	...
5B	2d tall fescue after corn	.68	.61	.66	.60	.82	.90	...	...
5C	1st corn after fescue	.72	.65	.63	.62	.58	.76	.93	.69
5D	2d corn after fescue	.62	.74	.70	.72	.78	.74	.81	.92
7A	1st tall fescue after corn	.68	.67	.82	.76	.80	.84	.76	.66
7B	2d tall fescue after corn	.75	.74	.79	.93	.86	.89	.73	.76
7C	3d tall fescue after corn	.68	.71	.70	.69	.86	.83	.76	.58
7D	Corn after 3 years fescue	.65	.75	.69	.64	1.02	.96	.78	.64
8A	1st coastal bermudagrass after corn	.65	.77	.71	.78	.70	.82	.82	.86
8B	2d coastal bermudagrass after corn	.96	.72	1.02	.91	.87	.84	.93	.86
8C	3d coastal bermudagrass after corn	.68	.74	.64	.85	.88	.92	.79	.65
8D	Corn after 3 years of coastal bermudagrass	.74	.75	.69	.69	1.14	.88	1.04	.81
9	Alfalfa sod	...	...	.74	...	.88	...	.81	...
10	Tall-fescue sod	.79	.79	.78	.95	1.00	1.14	.74	.77
11	Coastal-bermudagrass sod	.81	.78	.72	.85	1.18	1.08	.93	.70
12	Pensacola bahiagrass	.93	.88	.99	.87	1.22	1.14	.89	.94

was slightly higher in the perennial forage treatments than where annual crops of vetch and rye were grown. There was no clear-cut indication that removal of the cornstalks in treatments 1, 2, and 3 influenced the carbon content of the soil. Nor was there any indication that the differential in nitrogen to the corn affected the carbon in the soil.

A decline in carbon during the residual phase of the experiment (1966) was evident only where corn was grown following the perennial sods (treatments 10, 11, and 12).

(7) *Residual effects of cropping systems.*— Effects of vetch, rye, tall fescue, and coastal bermudagrass were apparent in corn yields 4 years after these crops were removed from the corn-cropping systems (table 8). Detailed analyses of these effects were limited because of the wide fluctuations in crop yields from year to year that resulted from variations in the June and July rainfall (table A–3). Rainfall totals for June and July of 9.55, 4.40, 13.72, and 7.31 inches for 1965, 1966, 1967, and 1968, respectively, are reflected in the yields shown in figure 6. Corn continuously yielded only 13 to 28 bu/acre without nitrogen, but yields increased with all other levels of N applied each year (except 1966), with a maximum of 142

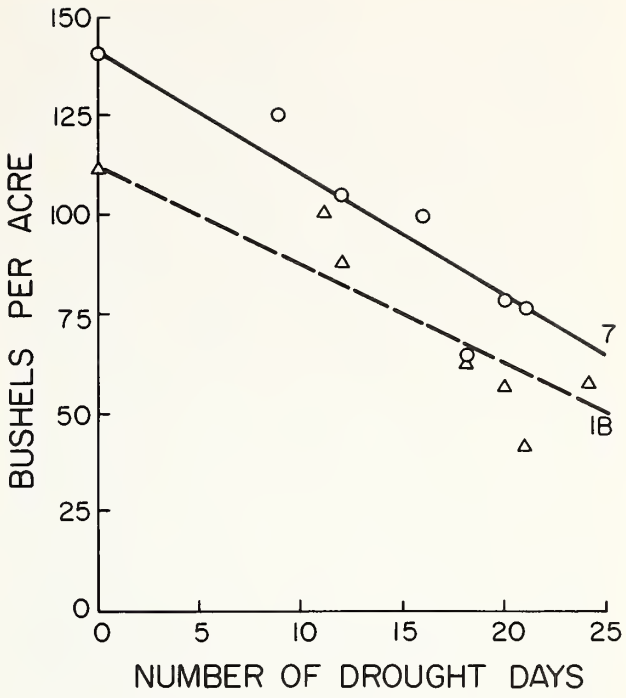

FIGURE 5.—Relation of corn yields to number of drought days in June and July with zero available soil water (80 lb N/acre) 1958–64.

TABLE 8.—*Yield of corn grown continuously after selected cropping systems were terminated following 1964 crop*

Treatment No.	Cropping treatment	Years of corn after corn	Years of record	Corn yield (bu/acre) at rate of nitrogen applied to corn (lb/acre)			
				0	40	80	160
1	Corn continuously	11–14	1965–68	19.5	52.8	66.1	80.2
2	Corn after vetch	11–14	1965–68	47.3	71.0	78.4	78.0
3	Corn after rye	11–14	1965–68	31.5	61.7	69.8	77.8
7	4-year rotation of fescue and clover 3 years, then corn:						
	1st corn after grass ..	0	1965–67	74.9	88.6	91.8	90.0
	2d corn after grass ..	1	1965–68	70.0	85.4	90.5	89.2
	3d corn after grass ..	2	1966–68	58.0	79.8	90.6	93.5
	4th corn after grass .	3	1967–68	49.2	91.2	122.8	114.9
	5th corn after grass .	4	1968	43.0	77.1	79.9	87.3
8	4-year rotation of coastal bermudagrass and clover 3 years, then corn:						
	1st corn after grass ..	0	1965–67	84.9	84.1	86.0	86.6
	2d corn after grass ..	1	1965–68	76.2	87.2	84.2	86.7
	3d corn after grass ..	2	1966–68	62.3	82.2	88.8	88.4
	4th corn after grass .	3	1967–68	59.0	101.8	115.8	115.2
	5th corn after grass .	4	1968	50.2	82.7	88.4	87.5

bu/acre with 160 lb N/acre measured in 1967 when soil water was adequate. There was little or no effect of N on yields from any treatment in 1966 when water was severely limited. Neither was there any response to any level of N on corn after vetch treatment in 1965, although there was no vetch turned that year. The effects of vetch lasted no more than 2 years, however, as shown by the response to N in 1967 and 1968 (fig. 6) for the corn following the previous vetch-corn treatment. The limited benefit from the previous rye green manuring at the 0-nitrogen level to corn diminished with increasing N until there was no benefit from the rye at 160 lb N/acre (treatment 1 versus treatment 3, table 8). Yields of corn following the grass-based rotations were higher than where corn was grown continuously (fig. 6), indicating that the effects of the grass lasted through several years of corn continuously after the rotation sequence was stopped. Yields of corn in 1968 were lower from the fifth year after grass than from the second year after grass (fig. 6) at all levels of N, indicating that the effects of the grass were diminishing by the fifth year. Responses of corn following coastal bermudagrass were similar to those discussed above for tall fescue.

The two rotations of alfalfa and corn (treatments 4 and 6) were terminated at the end of the 1960 crop year, and corn was grown continuously through 1967 on the plots where corn occurred in 1960. The plots in 1960 contained corn the first year after 2 years of alfalfa and corn after 1 year of corn in rotation 4, but only corn after 3 years of alfalfa in rotation 6. Therefore, in 1961, there was corn 1 year after corn following both rotations 4 and 6 and corn 2 years after corn following rotation 4. This difference in corn after corn held through the end of the study (table 9). Rates of N applied to the corn were 0, 40, 80, and 160 lb/acre.

Corn yields (table 9) varied widely from year to year as a result of variation in rainfall. There was no benefit to corn from the previous 3 years of alfalfa over the 2 years of alfalfa in rotations 6 and 4 in any year. There was only limited benefit from N applied to corn in 1961 and 1962 with the first and second and the second and third years of continuous corn after alfalfa. By 1963, however, in the third and fourth years of corn, the first 40 lb N/acre

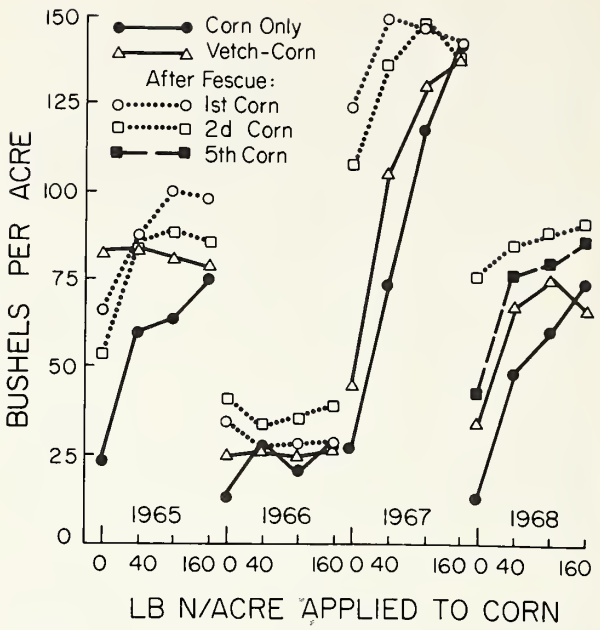

FIGURE 6.—Corn yields with four rates of nitrogen for 4 years after discontinuation of three separate rotations.

gave yield increases of 35 to 50 bu/acre, and in 1967 there was a similar response from 80 lb N/acre over the 40 lb N/acre. There was no benefit from 160 lb N/acre over 80 lb N/acre. These responses from N show that the yield-increasing benefits of the alfalfa began disappearing after two successive corn crops and were gone by the sixth to eighth crop.

Corn was grown without N in 1965–68 after 10 years of tall fescue, coastal bermudagrass, Pensacola bahiagrass, and alfalfa sods (table A–4). The three grasses had been overseeded with crimson clover each year. Nitrogen applied to the grasses included 80 lb/acre in 1955 through 1959 and 0, 80, 160, and 320 lb/acre in 1960 through 1964. Corn yields were higher all 4 years after alfalfa than after any of the grasses where 0 and 80 lb N/acre was applied to the sods, but this difference did not hold with the rates of 160 and 320 lb/acre (table 10). The yields tended to be higher following bahiagrass than the other two grasses all 4 years at the 0-nitrogen treatment, and for 3 years at the other N treatments. In the fourth corn year in 1968, the yields with the levels of 80, 160, and 320 lb N/acre were significantly higher from tall fescue than the other grasses and alfalfa.

TABLE 9.—*Yield of corn following alfalfa in rotation*

Year	Years of corn in succession	Corn yield (bu/acre) at rate of nitrogen applied (lb/acre) to corn for—							
		2-year cycle				3-year cycle			
		0	40	80	160	0	40	80	160
1961	1	125.5	129.5	136.9	133.3	106.2	125.0	126.1	134.5
	2	89.6	99.5	112.6	108.4	...	...	...	...
1962	2	63.3	57.0	62.5	63.8	51.4	59.0	64.9	65.8
	3	41.1	47.5	52.6	44.0	...	...	...	...
1963	3	67.6	102.9	105.8	108.5	64.5	115.1	105.4	112.7
	4	60.1	93.9	108.6	100.7	...	...	...	...
1964	4	55.3	100.7	119.0	109.0	43.9	94.8	124.0	126.5
	5	37.4	82.9	101.5	108.6	...	...	...	...
1965	5	47.7	85.7	88.3	83.0	44.3	73.0	81.9	76.6
	6	31.0	62.5	62.4	65.1	...	...	...	...
1966	6	19.5	33.3	20.0	29.0	22.3	31.4	27.3	30.9
	7	11.3	24.9	21.4	23.5	...	...	...	...
1967	7	44.1	104.0	136.3	140.0	36.3	80.3	127.7	128.0
	8	32.3	81.9	128.4	138.6	...	...	...	...

TABLE 10.—*Yield of corn with no nitrogen applied following 10 years of four perennial forage crops with four rates of nitrogen applied to the grasses*

Years of corn after plowing out forages	Forage crop[1]	Corn yield (bu/acre) at rate of nitrogen applied (lb/acre) to forages[2]			
		0	80	160	320
1	Tall fescue	68.2bc	78.6a*	76.5b*	83.6a*
	Coastal bermudagrass	72.8b*	70.8ab*	74.2bc*	80.2ab*
	Pensacola bahiagrass	73.3b*	73.5ab*	91.8a†	91.0a†
	Alfalfa	91.8a	...	...	...
2	Tall fescue	37.7g*	39.4d*	43.2de*	48.1d*
	Coastal bermudagrass	36.2g*	39.5d*	34.2e*	40.0d*
	Pensacola bahiagrass	44.4efg*	41.7d*	54.2ed*	47.8d*
	Alfalfa	51.2def	...	...	...
3	Tall fescue	57.2cde*	68.4ab*	72.8bc*	71.9bc*
	Coastal bermudagrass	61.3bcd*	65.0bc*	63.0cd*	67.3bc*
	Pensacola bahiagrass	69.7bc*	71.0ab*	84.5ab†	87.6a†
	Alfalfa	96.0a	...	...	...
4	Tall fescue	43.0fg	77.1ab*	79.9ab*	87.3a*
	Coastal bermudagrass	42.5fg*	52.4cd*	48.8d*	44.5d*
	Pensacola bahiagrass	50.1def*	44.7d*	50.3cd*	62.0c*
	Alfalfa	63.0bcd	...	...	...

[1] Crimson clover was overseeded each year on all 3 grasses.

[2] No nitrogen applied to alfalfa, 1955–64; 80 lb N/acre applied to all 3 grasses, 1955–64; 0, 180, and 360 lb N/acre applied to all 3 grasses, 1960–61; 1st corn crop, 1965. Values in a column followed by the same letter are not significantly different at the 95% level. Values within a cropping treatment followed by the same symbol are not significantly different at the 95% level.

Runoff Plots

TREATMENTS. — Measurements of rainfall amount and intensity, runoff amount, and soil losses were made by individual rainstorms on runoff plots with six cropping treatments, some of which were similar to the crop systems listed in the previous section. The complete array of cropping treatments was (1) fallow soil cultivated annually with no vegetative cover, (2) cotton continuously, (3) corn continuously, (4) 3-year rotation of coastal bermudagrass 2 years, then corn, (5) 3-year rotation of tall fescue 2 years, then corn, (6) 4-year rotation of tall fescue 2 years, corn, cotton.

The fescue was reseeded following the row crop in the rotations. Comparisons of crop rows with the slope versus across the slope (on contour) were included in cropping treatments of cotton and corn continuously and the 3-year rotation of coastal bermudagrass and corn. Crop rows were on the contour only in the fescue rotations. The slope length was 70 feet for all treatments. The slope was 3, 7, and 11 percent on the corn continuously and 3 and 7 percent only on all other treatments. The Cecil soil was a sandy loam texture on 30 plots and a sandy clay loam on 10 plots. This increased clay content resulted from more erosion earlier on the site of those specific plots, causing a mixing of some subsoil with the remaining topsoil as the land was plowed. Each crop in a given rotation appeared on successive plots within the rotation sequence from year to year. This system caused a rotation of crops between the sandy loam and sandy clay loam areas, thereby evening out the effects of these soil differences over a period of several years. All crops in each rotation sequence appeared on duplicate plots each year. Data for any year of record represented all crop years in a given cropping cycle.

Each plot was 21 feet wide to allow for the use of normal field equipment and production practices. The plots were separated from the surrounding area by earthen ridges at the top and along the sides. Troughs at the lower end delivered runoff water to storage tanks downslope. Runoff and soil losses were measured after each significant storm and tabulated by storms, months, seasons, and years. Erosion index (EI) values (*21*) were computed for each storm and tabulated for each year of record. The erosion index, which is the product of the kinetic energy of the storm times the maximum 30-minute intensity, is an interaction term that indicates the potential of the raindrop impact and overland flow to dislodge and transport soil particles.

Plots were limed on an individual basis, as needed, to maintain a pH level of 6.5. Applications of nitrogen, phosphorus, and potassium ($N–P_2O_5–K_2O$) in pounds per acre to the various crops were:

Fallow: no fertilizer and no lime.
Cotton and corn:
- 0–50–100 broadcast before turning.
- 20–50–100 in row at planting.
- 60–0–0 at second cultivation.

Tall fescue and crimson clover seeded after corn:
- 0–50–100 after corn harvest.
- 20–50–100 at seeding.
- 60–0–0 total, in two equal applications (February and March).

Second-year fescue and clover:
- 0–50–100 in September.
- 0–50–100 in February.
- 80–0–0 total, in three equal applications (September, February and March).

Coastal bermudagrass and crimson clover after corn:
- 0–50–100 after corn harvest.
- 20–50–100 after clover harvest in April.
- 60–0–0 total, in three equal applications after grass hay harvest.

Second-year coastal bermudagrass and clover:
- 0–50–100 in fall for clover.
- 20–50–100 after clover harvest in spring.
- 60–0–0 total, in three equal applications after grass hay harvests.

Land preparation, seeding, cultivation, harvesting, and other operations were performed by normal equipment in a conventional manner. Hay was harvested from the grasses and clover, but the cotton and cornstalks were left on the land after harvest. Earthen ridges around the plots were re-formed by hand after each operation on the plots.

RESEARCH RESULTS.—Annual rainfall varied from 35.48 inches in 1965 to 72.34 inches in 1964 and averaged about 55 inches for the 5 to 7 years of record for these studies. Erosion index values of the rain varied from 177 in 1965 to 579 in 1964 and 1961, with the 7-year average being 381 (table A–5). This value was about 100 EI units higher than the longtime value reported by Wischmier and Smith (*22*) for this location.

Average annual runoff was 18.35 inches from the fallow soil, 9.84 inches from cotton continuously, and 7.03 inches from corn continuously, with rows up and downslope (table 11). Contouring reduced water losses by one-third from the continuous row crops and the corn after 2 years of coastal bermudagrass. Runoff was only about 2 inches per year from the bermudagrass, 3 to 4 inches from corn after the bermudagrass, and 5.4 inches from the first year of tall fescue following 1 year of corn. The addition of a year of cotton after the corn caused water losses in the first and second years of grass to be double those under similar conditions after only 1 year of corn.

Annual soil losses from the fallow soil ranged from 20 tons per acre in 1965 to 98 tons per acre in 1961 and averaged 60.43 tons per acre. The annual soil losses were related to annual EI values (fig. 7) by the expression

$$Y = 0.167X, \quad (3)$$

where Y is the annual soil loss and X the annual EI value.

The average annual soil losses of 21.86 and 12.11 tons per acre from cotton and corn, respectively (rows with the slope, table 11), show the tremendous effect of plant canopy and residue on the reduction of soil losses, compared with the 60.43 tons per acre from fallow. Sod crops turned ahead of row crops further reduced the soil loss to 1 to 3 tons per acre. The soil loss of 6.25 tons per acre from cotton after corn in the 4-year rotation (table 11), when compared with 4.02 tons per acre for corn continuously, showed that the benefit from grass was partially gone by the second year of row crops after grass.

Extremely low soil losses of less than 0.2 ton per acre were measured from well-established sod, whereas the losses from first-year sod were 1 to 2 tons per acre where the grass followed 1 year of row crop and 4 tons per acre where the grass was established after two row crops (rotation 6 in table 11). Soil loss from corn continuously with rows uphill and downhill was directly proportional to the land slope (fig. 8). This relationship was expressed as

$$Y = 2.31X - 4.6, \quad (4)$$

where Y is the average annual soil loss in tons per acre, and X the land slope in percent. There was no consistent relationship between runoff and land slope.

Soil Erodibility

TREATMENTS.—Soil-erodibility measurements were made on selected soils in Georgia, South Carolina, and Alabama with a rainfall simulator. This machine was designed to apply simulated rain at selected intensity × amount patterns for prescribed EI values. Representative test sites for bench-mark soils were selected

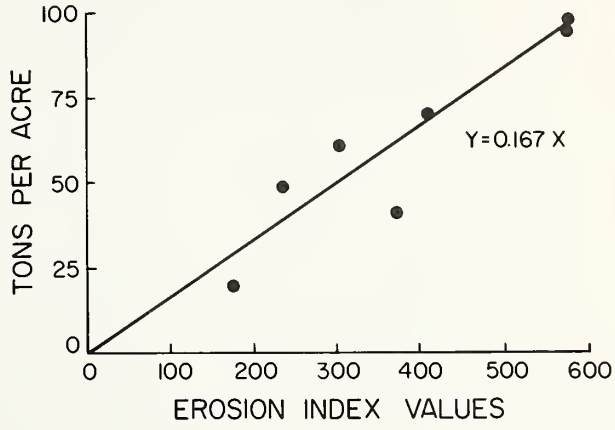

FIGURE 7.—Relation of soil loss to erosion index on fallow Cecil sandy loam, 7-percent slope, 70-foot length.

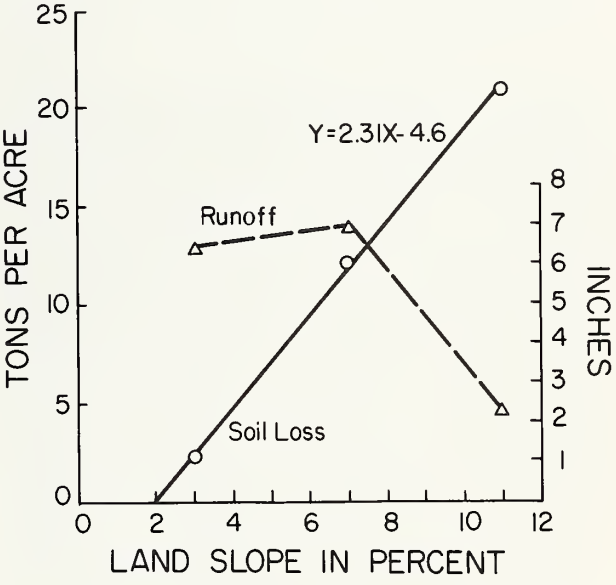

FIGURE 8.—Average annual runoff and soil loss from corn continuously with rows uphill and downhill on slopes of 3, 7, and 11 percent and 70-foot length on Cecil sandy loam.

TABLE 11.—*Average annual rainfall, runoff, and soil loss by cropping treatment*

Treatment No.[1]	Cropping treatment	Slope (percent)	Row direction[2]	Rainfall (inches)	Runoff (inches)	Soil loss (tons/acre)
1	Fallow	7	([3])	55.71	18.35	60.43
2A	Cotton continuously	7	A	55.71	6.33	12.28
2B	..... do	7	W	55.71	9.84	21.86
3A	Corn continuously	7	A	55.71	4.54	4.02
3B	..... do	3	W	55.71	6.54	2.40
3B	..... do	7	W	55.71	7.03	12.11
3B	..... do	11	W	55.71	2.40	20.90
4A	3-year rotation of—					
	1st coastal bermudagrass	7	([3])	54.78	2.42	1.99
	2d coastal bermudagrass	7	([3])	54.78	1.78	.16
	Corn	7	W	54.78	4.42	4.43
	Rotation average	7	W	54.78	2.87	2.19
4B	3-year rotation of—					
	1st coastal bermudagrass	7	([3])	54.78	2.25	2.26
	2d coastal bermudagrass	7	([3])	54.78	2.74	.19
	Corn	7	A	54.78	2.99	1.08
	Rotation average	7	A	54.78	2.66	1.17
5	3-year rotation of—					
	1st tall fescue	7	([3])	56.73	5.42	.88
	2d tall fescue	7	([3])	56.73	2.80	.09
	Corn	7	A	56.73	4.56	1.97
	Rotation average	7	A	56.73	4.26	.98
6	4-year rotation of—					
	1st tall fescue	7	([3])	57.56	11.04	4.05
	2d tall fescue	7	([3])	57.56	5.07	.05
	Corn	7	A	57.56	6.04	2.93
	Cotton	7	A	57.56	7.23	6.25
	Rotation average	7	A	57.56	7.34	3.32

[1] Years of record: treatment numbers 1–3, 1961–67; treatment number 4, 1962–67; treatment numbers 5 and 6, 1961–65.

[2] A = rows on contour across slope; W = rows uphill and downhill with the slope.

[3] No rows.

and profile descriptions written by soil scientists of the Soil Conservation Service (SCS). Prescribed storms of known intensity and amounts were applied. Soil losses in the resulting runoff were measured. The *K*-value of each site tested was reported as soil loss per EI unit (tons/acre/EI) for standard conditions of fallow soil on a 9-percent slope, 72.6 feet long.

RESEARCH RESULTS.—The 19 soil series in 4 land resource areas of the Southeast where soil-erodibility studies were conducted with the rainfall simulator on 1 to 4 sites are listed in table 12. The resulting *K*-values ranged from 0.06 ton/acre/EI for Vaiden clay to 0.67 ton/acre/EI for Red Bay sandy loam (table 12). Analyses of data from these measurements with the simulator showed that the results were affected by many soil and site factors. Land slope was the dominant factor. Others included the depth of the A horizon; bulk density, organic matter, and antecedent soil water in surface soil; soil separates (texture); and 50- and 20-micron-suspension percentages. Also, there were significant interactions between some of these factors. A formula expressing the relationships between these factors took the form

$$K = (a + bX_1 + cX_2 + dX_3 + \ldots + mX_n) / (SL \times C), \quad (5)$$

where K=tons/acre/EI; $a, b, \ldots, m$ are parameter coefficients; $X_1, X_2, \ldots, X_n$ are the several parameters and their interactions; and SL and C are the slope-length and cropping factors from Wischmier and Smith (*22*). Barnett et al. (*7*) discussed the 18 parameters listed below and showed that the interactions of certain ones could be arranged in a complicated linear form to predict the erodibility of a soil. These 18 parameters are (1) land slope in percent, (2) depth of the A horizon in

TABLE 12.—*K-factor value of soils measured with the rainfall simulator and by laboratory determinations*

Land resource area	Series	Texture[1]	*K*-factor
Southern Piedmont	Georgeville	sil	0.40–0.50
	Iredell	fsl-scl	0.20–0.42
	Helena	ls-csl	0.29–0.39
	Herndon	sil-gr sil	0.25–0.33
	Mecklenburg	scl	0.28
	Cecil	sl-scl	0.23–0.25
	Lloyd	scl	0.14–0.21
Southern Coastal Plain	Red Bay	scl-sl	0.24–0.67
	Malbis	sl-scl	0.56–0.60
	Dothan	sl	0.21–0.46
	Ruston[2]	sl-l	0.30–0.39
	Tifton	ls-sl	0.13–0.30
	Providence[2]	sil	0.14–0.29
	Norfolk	lcs-sl	0.14–0.24
	Lakeland	ls-sl	0.09–0.22
	Faceville	ls	0.20
	Marlboro	ls-gr sl	0.13–0.17
Alabama and Mississippi blackland prairies	West Point	cl	0.36
	Sumter	cl	0.35
	Oktibbeha	cl	0.23
	Vaiden	cl	0.06
Southern Mississippi Valley silty upland	Loring[2]	sil	0.40–0.48
	Granada[2]	sil	0.25–0.43

[1] Sil=silt loam; fsl=fine sandy loam; scl=sandy clay loam; ls=loamy sand; gr sil=gravelly silt loam; sl=sandy loam; l=loam; lcs=loamy coarse sand; cl=clay loam.

[2] By laboratory determination. All others were with rainfall simulator.

inches, (3) bulk density in grams per cubic centimeter, (4) percentage of carbon in surface soil, (5) percentage of moisture of surface soil at one-third bar suction, (6) percentage of moisture of surface soil at 15 bars suction, (7) percentage of gravel 2 to 4.76 mm, (8) percentage of very coarse sand 1 to 2 mm, (9) percentage of coarse sand 0.5 to 1.0 mm, (10) percentage of medium sand 0.25 to 0.5 mm, (11) percentage of fine sand 0.1 to 0.25 mm, (12) percentage of very fine sand 0.05 to 0.1 mm, (13) percentage of total sand 0.02 to 2.0 mm, (14) percentage of silt 0.002 to 0.05 mm, (15) percentage of clay less than 0.002 mm, (16) 50-micron-suspension percentage, (17) 20-micron-suspension percentage, and (18) percentage of antecedent soil moisture in surface soil.

The *K*-values for Ruston, Providence, Loring, and Granada soil series in table 12 were obtained from measurements of parameters 1 and 2 made in the field and 3 through 18 in the laboratory. These 4 *K*-values are considered less reliable than the other 19 because the reliability of the formula used was not tested fully.

Unit Watershed

TREATMENTS.—Rainfall and runoff were measured on a unit watershed of 19.2 acres.

TABLE 13.—*Rainfall and runoff on a 19.2-acre watershed in coastal bermudagrass*

Year	Rainfall[1] (inches)	Runoff	
		Inches	Percentage of rainfall run off
1964	72.37	15.73	21.7
1965	36.14	.11	.3
1966	49.34	5.09	10.3
1967	57.15	2.10	3.7
1968	47.82	.68	1.4
1969	52.49	2.11	4.0
1970	39.47	1.19	3.0
1971	60.86	2.21	3.6
Average	51.96	3.65	7.1

[1] Average, 1881–1971, 49.49 in.

Land slopes ranged from 3 to 10 percent and averaged 7 percent. The longest drainage line from crest to gaging site was 1,300 feet. An excellent stand of coastal bermudagrass on the field was grazed throughout the 1964–71 period of record.

RESEARCH RESULTS.—Rainfall on the 19.2-acre unit watershed varied from 72.37 inches in 1964 to 36.14 inches in 1965. Runoff from the coastal bermudagrass varied from 15.73 inches to 0.11 inches for the same years (table 13). Of this 15.73 inches of runoff, 14.10 inches were measured in March, April, May, and July from 39.21 inches of rain. This amount of rain, which was 220 percent of the normal for those 4 months, so saturated the soil that 36 percent ran off the land. The average annual rainfall and runoff are 51.96 and 3.65 inches, respectively. The long-time average rainfall for this area is 49.49 inches. There was no indication of erosion on the field or in the runoff water any year, even though this good ground cover of bermudagrass was utilized fully for grazing beef cattle and hay harvests.

BERMUDAGRASS FOR FORAGE

Experiments with bermudagrass for forage were conducted on class II land with Cecil sandy loam topsoil. A good sod was established before the respective treatments were applied. Several types of studies, with treatments and research results, are described below.

Comparison of Common and Coastal Bermudagrasses With and Without Overseeded Crimson Clover at 10 Levels of Fertility

TREATMENTS.—Dolomitic limestone was broadcast at 1 ton per acre with phosphorus and potassium at the rates shown in table 14 and disked into the soil ahead of sprigging the grasses in April. Nitrogen was applied as ammonium nitrate in three equal applications to give 100 lb N/acre uniformly the first year. All subsequent P and K was applied in the fall during the seeding of crimson clover, and N was applied to the grass in three or four increments after the crimson clover harvest at full bloom and subsequent grass hay harvests. All treatments were replicated four times. Forage yields were taken by mowing a swath 34 inches wide and 15 feet long in each plot at time intervals of about 5 weeks throughout the summer. All yields were recorded on the ovendry basis. The experiment was run for 3 years.

RESEARCH RESULTS.—(*1*) *Yields.*—Forage yield from coastal bermudagrass was 50 to 70 percent greater than from common bermudagrass at similar fertility levels. Crimson clover overseeded on the grasses stimulated the grasses at the lower fertility rates but had little effect on them at the higher rates of N–P–K (fig. 9). Each increment of N alone and the N–P–K combination gave yield increases with both grasses, whereas an increase

TABLE 14.—*Yields of common and coastal bermudagrasses with and without crimson clover at different fertility levels*

[Tons per acre]

Fertility level: $N–P_2O_5–K_2O$ (lb/acre)	Common			Coastal		
	Without clover	With clover		Without clover	With clover	
		Grass only	Grass & clover		Grass only	Grass & clover
0–0–0	0.90	1.36	2.82	1.44	2.07	3.29
0–100–100	1.16	1.40	3.07	1.65	2.44	4.03
50–0–0	1.54	1.74	3.09	2.54	3.03	4.19
50–50–50	1.53	1.99	3.53	3.02	3.42	4.97
100–50–50	2.27	2.68	4.23	3.88	4.23	5.67
200–50–50	3.34	3.42	4.86	5.82	5.09	6.38
200–100–100	3.74	3.63	5.08	5.64	5.80	7.20
400–0–0	3.47	2.96	3.96	5.40	4.78	5.45
400–100–100	4.67	3.98	5.16	6.96	6.50	7.64
400–200–200	4.85	4.40	5.50	7.50	7.50	8.52

of P or K without N had little effect on grass production. Amounts of grass harvested (tons per acre) at the 0–0–0 fertility level were 0.90 and 1.36 for common bermudagrass and 1.44 and 2.07 for coastal bermudagrass, both without and with clover, respectively. Results at 100–50–50 N–P_2O_5–K_2O were 2.27 and 2.68 for common bermudagrass and 3.88 and 4.23 for coastal bermudagrass. Increasing the fertilizer to 400–200–200 gave 4.85 and 4.40 with common bermudagrass and 7.50 and 7.50 with coastal bermudagrass (tables 14 and A–6). Crimson clover increased total forage production with both grasses (fig. 9). Total production of common bermudagrass without and with clover respectively, at different levels of N–P_2O_5–K_2O was 0.90 and 2.82 at 0–0–0, 2.27 and 4.23 at 100–50–50, 3.74 and 5.08 at 200–100–100, and 4.85 and 5.50 at 400–200–200. The production of coastal bermudagrass under similar conditions was 1.44 and 3.29 at 0–0–0, 3.88 and 5.67 at 100–50–50, 5.64 and 7.20 at 200–100–100, and 7.50 and 8.52 at 400–200–200. The addition of crimson clover also extended the forage production period about 2 months over grass alone.

(*2*) *Soil fertility.*—Soil analyses following 3 years of grass showed that available potassium was reduced by increased levels of N and increased by levels of K_2O added to the grasses. Data in table 15 show that with no K_2O added the level of K_2O in the soil under coastal bermudagrass was 43, 25, 20, and 15 lb/acre where 0, 100, 200, and 400 lb N/acre, respectively, was applied. However, when 200 lb K_2O/acre was added, the K_2O in the soil was 203, 144, 105,

TABLE 15.—*Available potassium* (K_2O) *in the soil when coastal bermudagrass was grown for 3 years with different rates of nitrogen and potassium applied to the soil*

Annual rate of K_2O (lb/acre)	Potassium available (lb/acre) at rate of nitrogen applied (lb/acre)			
	0	100	200	400
0	43	25	20	15
50	88	43	25	24
100	125	61	40	32
200	203	144	105	85

TABLE 16.—*Effect of nitrogen and potassium on stand of coastal bermudagrass*

[Percent stand]

Annual rate of K_2O (lb/acre)	Nitrogen applied (lb/acre)			
	0	100	200	400
0	88	83	62	35
50	91	86	75	46
100	93	90	82	61
200	93	91	83	76

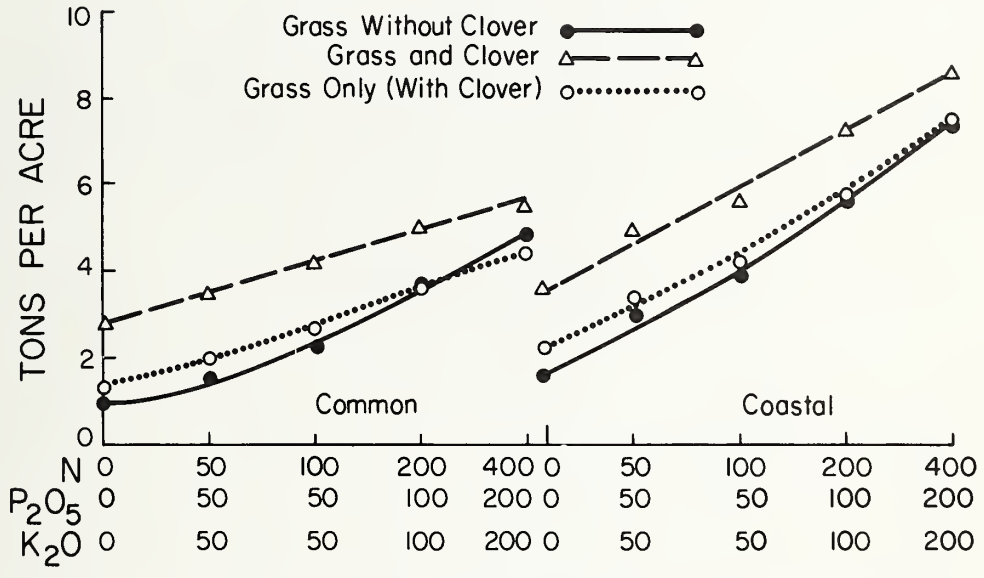

FIGURE 9.—Yields of common and coastal bermudagrasses at different fertility levels, with and without crimson clover.

and 85 lb/acre where 0, 100, 200, and 400 lb N/acre respectively, was added.

(*3*) *Stand.*—Injury on coastal bermudagrass was observed following colder than normal weather in the winter after 3 years of grass production. Determinations the following June after grass recovery showed that the stand was reduced as the rates of N increased and increased with greater rates of K_2O (table 16). The best stand of the grass occurred with high K_2O and low N. These results lead to the study reported under in the following section.

Nitrogen, Phosphorus, and Potassium Requirements of Coastal Bermudagrass and Crimson Clover

TREATMENTS.—Grass and clover were established and treated as described in the above section, except the fertility treatments included four rates each of N, P_2O_5, and K_2O in lb/acre as follows: 0–0–0; 100–50–50; 200–100–100; and 400–200–200. Every possible combination of these rates in a 4×4×4 factorial experiment gave 64 treatments per replication, with 3 replications used. Half the P and K was applied in the fall and half after the clover harvest in April each year. The N was applied in split applications after the grass hay harvests.

RESEARCH RESULTS.—Treatments included a 4×4×4 factorial arrangement of N–P_2O_5–K_2O at rates of 0–0–0, 100–50–50, 200–100–100, and 400–200–200 lb/acre, with 3 replications.

(*1*) *Yields.*—From the 64 treatments in this 4×4×4 factorial arrangement, yields showed a positive response of grass to the N, P, and K and to interactions of these elements (table A–7). The 3-year-average range in grass yield was from 1.98 tons per acre with 0–0–0 to 7.32 tons per acre with 400–200–200 N–P_2O_5–K_2O (table 17). The greatest response was from N, and grass yields increased as the N rate increased at any level of P_2O_5 and K_2O. However, the response from N was greater at high levels of P_2O_5 and K_2O than at low levels of these elements. There was little or no response of grass to the P_2O_5 without K_2O at any level of N, but there was a positive response to K_2O at all levels of N and P_2O_5.

Nitrogen applied to the grass had an adverse effect on yield of crimson clover, especially at low levels of K_2O. The clover yield was increased as rate of K_2O was increased, but the largest increment was with the first 50 lb K_2O/acre. Actual yields ranged from 0.50 ton per acre with 400–200–0 to 1.48 tons per acre with 0–50–200 N–P_2O_5–K_2O. Potassium deficiency was observed on all clover with low K_2O, with increased severity at high N levels.

(*2*) *Soil fertility.*—Chemical analyses of the soil after 3 years of the grass and clover

TABLE 17.—*Yields of coastal bermudagrass and crimson clover with different levels of nitrogen, phosphorus, and potassium, 3-year average*

P_2O_5 (lb/acre)	K_2O (lb/acre)	Crimson-clover yield (tons/acre) for nitrogen (lb/acre) applied to coastal bermudagrass				Coastal-bermudagrass yield (tons/acre) for nitrogen (lb/acre) applied to coastal bermudagrass			
		0	100	200	400	0	100	200	400
0	0	1.01	0.96	0.72	0.55	1.98	3.89	4.40	4.43
0	50	1.20	1.11	.91	.78	2.13	3.91	4.91	5.31
0	100	1.23	1.06	.98	.83	2.19	3.66	5.10	5.16
0	200	1.17	1.08	.82	.84	1.97	4.07	5.23	5.88
50	0	1.08	.96	.90	.56	2.38	4.35	5.00	4.95
50	50	1.30	1.32	1.19	1.01	2.25	4.59	5.64	6.27
50	100	1.38	1.42	1.14	1.02	2.11	4.48	5.68	6.48
50	200	1.48	1.44	1.30	1.06	2.60	4.55	5.60	6.55
100	0	1.11	.78	.79	.62	2.19	4.14	4.77	5.22
100	50	1.40	1.25	1.11	.89	2.56	4.36	5.69	6.27
100	100	1.28	1.47	1.14	.95	2.22	4.56	5.80	6.35
100	200	1.38	1.39	1.26	1.05	2.46	4.35	6.07	6.72
200	0	.99	.71	.55	.50	2.22	4.26	5.17	5.66
200	50	1.10	1.33	.94	.77	2.45	4.71	5.50	6.25
200	100	1.13	1.18	.96	.82	2.94	4.83	5.85	7.11
200	200	1.22	1.34	1.13	1.04	2.48	4.85	6.44	7.32

showed that pH and extractable K_2O in the soil declined as N was increased but that N had no consistent effect on extractable P_2O_5. Extractable P_2O_5 increased with higher rates of P_2O_5 added to the soil, but extractable K_2O was not affected by the added P_2O_5. Likewise, the extractable K_2O in the soil was increased with higher rates of K_2O added, but extractable P_2O_5 was not affected.

(*3*) *Nutrient uptake.*—Chemical analyses of the grass from the third year of the study showed that N rate directly affected N uptake but had an inverse effect on P and K uptake by the grass. Rates of P_2O_5 and K_2O had little or no effect on N uptake, but the uptake of either P or K was reduced slightly as the other element was increased in the soil. The uptake of either P or K was increased materially as that element was increased in the soil. Table 18 gives the percentage of concentration and the total pounds of N, P, and K per acre in the forage harvested for selected treatments during the third year of this study. Phosphorus and potassium fertilization also increased the percentage of applied N recovered in the harvested crop.

TABLE 18.—*Uptake of nitrogen, phosphorus, and potassium by coastal bermudagrass with different rates of* N, P_2O_5, *and* K_2O *fertilizer*

Fertilizer: N–P_2O_5–K_2O (lb/acre)	Nitrogen		Phosphorus		Potassium	
	%	lb/acre	%	lb/acre	%	lb/acre
0–0–0	1.47	47	0.22	7	1.21	39
400–0–200	2.27	258	.16	18	2.07	235
400–200–50	2.50	298	.25	30	1.02	122
400–200–200	2.44	369	.26	39	1.91	288

The yield responses, together with the chemical analyses, in this study indicate that liming is essential to control the pH level and that phosphorus and potassium must be applied in proportion to nitrogen. A 2:1:1 ratio of N:P_2O_5:K_2O appears to be satisfactory. The yields of grass and crimson clover for four levels of fertility with this ratio in table 19 show that grass yield increased with added fertility levels but that clover yield declined slightly after the 100–50–50 level. Addition of the grass and clover yields gives the total forage production for any of these four fertilizer treatments.

Response of Coastal Bermudagrass to Irrigation, Clipping Frequency, and Level of Fertility

TREATMENTS.—Plots were located in a well-established stand of coastal bermudagrass. The experimental design and treatments included: (1) whole plot=level of soil water=2=rainfall only versus rainfall+irrigation, (2) split plot=clipping frequency=3=2 weeks versus 4 weeks versus 6 weeks, (3) split-split plot=fertility level=3 rates of N–K at ratios of 1:1, 2:1, and 6:1, with N–K rates in lb/acre of 200–200, 200–100, 200–34, 600–600, 600–300, 600–100, 1,000–1,000, 1,000–500, and 1,000–167.[5] Fertilizers containing N–K were applied in equal increments prior to each cycle (12 equal applications for the 2-week, 6 for the 4-week, and 4 for the 6-week clip frequency. Replications=4.

A uniform application of superphosphate to

[5] Multiply these lb K/acre rates by 1.20 for lb K_2O/acre.

TABLE 19.—*Yields of crimson clover and coastal bermudagrass by years with different fertilizer treatments*

[Tons per acre]

Year	N–P_2O_5–K_2O (lb/acre)							
	0–0–0		100–50–50		200–100–100		400–200–200	
	Clover	Grass	Clover	Grass	Clover	Grass	Clover	Grass
1955	1.14	2.77	1.50	5.30	1.28	6.16	1.41	6.93
1956	.51	1.58	.92	4.40	.73	5.55	.51	7.49
1957	1.39	1.60	1.54	4.06	1.50	5.54	1.21	7.54
Average	1.01	1.98	1.32	4.59	1.17	5.75	1.04	7.32

give 200 lb P_2O_5/acre (87 lb P/acre) was made to all plots in April each year. The source of nitrogen was A–N–L (ammonium-nitrate-lime) to maintain a satisfactory pH level, and the source of potash was potassium sulfate (K_2SO_4). The N and K materials were applied in split applications following each harvest to give the desired amount over the growing season. Lime was applied as needed to maintain a pH level of 6.5.

Soil-water desorption curves were obtained by standard laboratory procedures with undisturbed soil cores in the pressure plate and membrane apparatus. Field capacity of the soil was determined as the soil-water content of soil samples taken 2 days after a rain in March that fully wet the soil profile. Available water capacity was computed from the water content at field capacity and at 15 bars suction. The need for irrigation was determined with electrical resistance blocks imbedded at the midpoint of the soil depths of 0–6, 6–12, 12–18, and 18–24 inches in the 2:1 N–K fertility treatments on all three clipping frequencies. Electrical resistance meter readings were converted to inches of water present. Water was applied to all fertility and clipping treatments with sprinklers to restore the soil profile to field capacity in the top 24 inches when 50 percent of the available water was depleted at that depth.

The clipping cycles for forage harvest were started in May after growth of the grass began and ended in late September after 12, 6, and 4 cycles, respectively, of the 2-, 4-, and 6-week intervals. The forage was dried in the oven at 65° C, and yields were reported on the ovendry basis for the 1964–67, 4-year period.

RESEARCH RESULTS.—(*1*) *Soil water.*—Soil-water content at field capacity (when wet but not saturated) totaled 2.04 inches for the top 24 inches of soil depth, with 0.68, 0.53, 0.45, and 0.38 inch in the layers of 0–6, 6–12, 12–18, and 18–24 inches, respectively, in the Cecil sandy loam where this study was located. The tension at which this water was held at field capacity was 0.10, 0.12, 0.16, and 0.20 bar for these different layers. Half the amount of available water was held at a tension of about 1 bar in the 0- to 6-inch layer and at 2 to 3 bars in the deeper layers (fig. 10).

Rainfall records during the 4 years of this study showed that rain was adequate but poorly distributed in 1964, inadequate in 1965 and

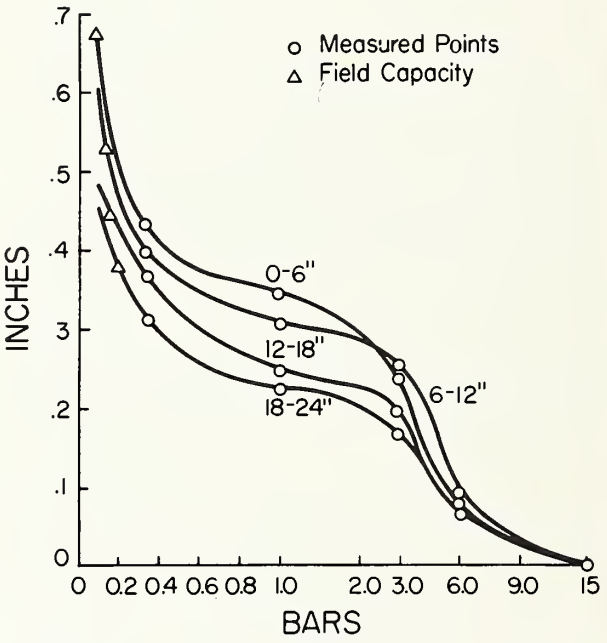

FIGURE 10.—Soil-water content by layers at different suction levels in Cecil sandy loam.

TABLE 20.—*Rate of water loss from Cecil soil with three fertilizer levels and three clipping frequencies on irrigated coastal bermudagrass during periods without rain or irrigation in 1966*

Period	Water loss (in/d) at rate of nitrogen-potassium applied (lb/acre)								
	2-wk clipping interval			4-wk clipping interval			6-wk clipping interval		
	200–100	600–300	1,000–500	200–100	600–300	1,000–500	200–100	600–300	1,000–500
June 20–29	0.057	0.088	0.103	0.067	0.086	0.069	0.067	0.068	0.092
July 4–14	.080	.070	.109	.085	.127	.100	.081	.135	.141
July 21–27	.082	.100	.177	.098	.087	...	.093	.197	.103
Aug. 10–31	.052	.058	.081	.087	.025	.018	.065	.103	.104
Sept. 5–12	.066	.054	.103	.116	.059	.047	.023	.027	.009
Oct. 11–17	.045	.038	.055	.047	.042	.017	.042	.068	.070

1966, and adequate and well distributed in 1967. Thus, irrigation was needed 3 out of 4 years.

Soil-water measurements to 48 inches in 1964 showed that most of the water used by the grass was from the top 24 inches of soil that year. Irrigations maintained some available water in all soil layers throughout the growing season each year (fig. 11). Available water was depleted completely from the 24-inch depth part of each season in 1965 and 1966 where there was no irrigation (fig. 12). Rates of water loss from the root zone were high 1 or 2 days following a rain or irrigation and low during periods when no water was added to the soil. A lack of correlation between changes in soil-water content and the evapotranspiration equivalent of solar radiation indicated that some water was lost by deep percolation from the root zone shortly after some rains and irrigations and that the transporting capacity of the soil was inadequate for meeting the radiative demand when the soil was partially dried

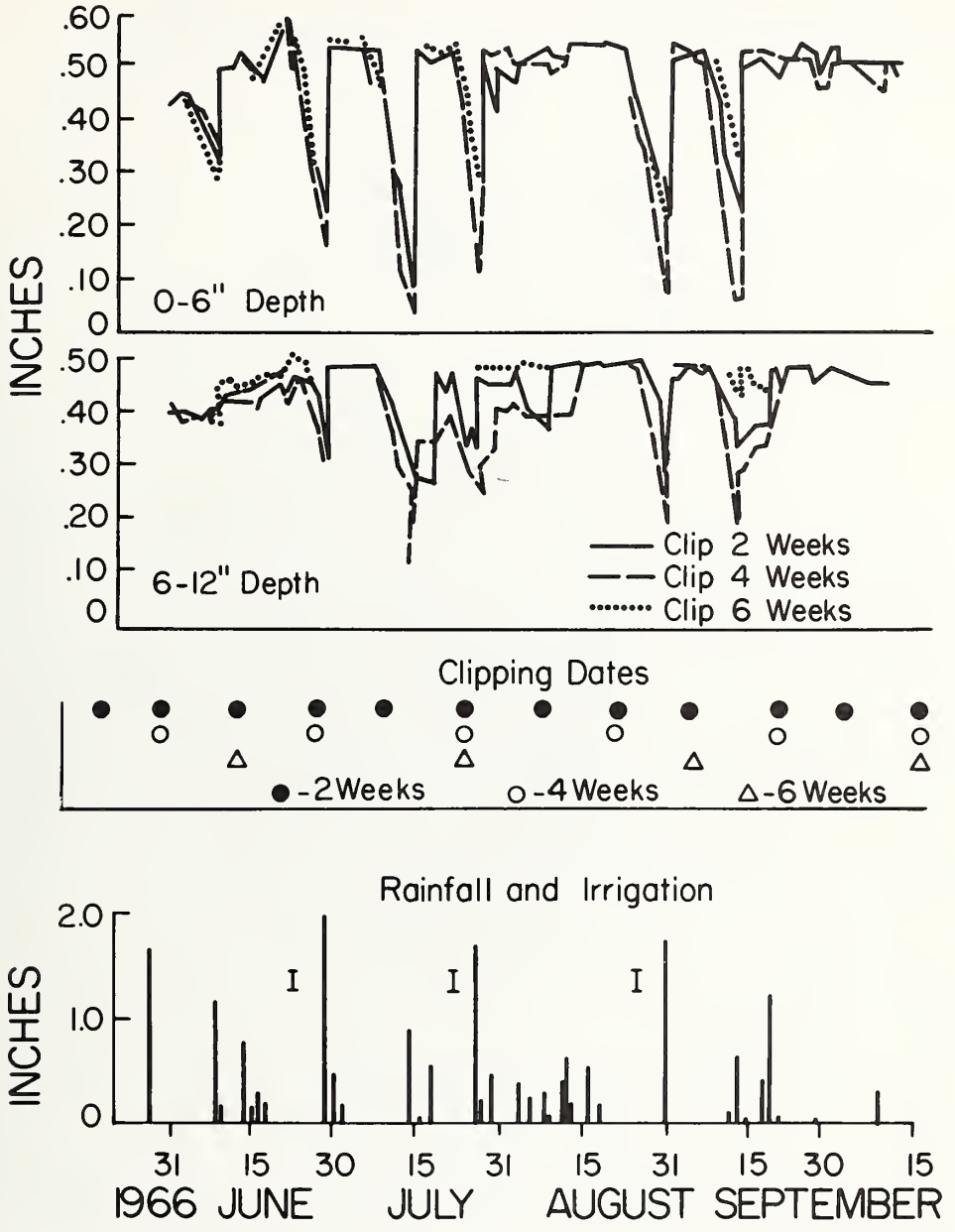

FIGURE 11.—Rainfall, irrigation, and soil-water content by days in 1966 under coastal bermudagrass with application of 200–100 lb nitrogen and potassium per acre.

out. Rates of water loss from the irrigated soil varied from a low of about 0.04 to almost 0.20 inch per day during short periods when neither rain nor irrigation affected water use (table 20). There was no consistent effect of clipping frequency or fertility level on the rate of water use. Soil-water content was affected to a slight degree by clipping frequency and fertility level when sustained growth was made possible by irrigation, but no such relationships existed where growth was interrupted in dry soil resulting from inadequate rainfall.

(*2*) *Water use.*—Total water used from early May to the middle of October 1966 was 10 and 14 inches, respectively, by the unirrigated and irrigated treatments. Fertility level had no effect on water use at the 2- and 6-week clipping interval, but there was a slight tendency toward reduced water use with increased fertility on the 4-week clipping (fig. 13).

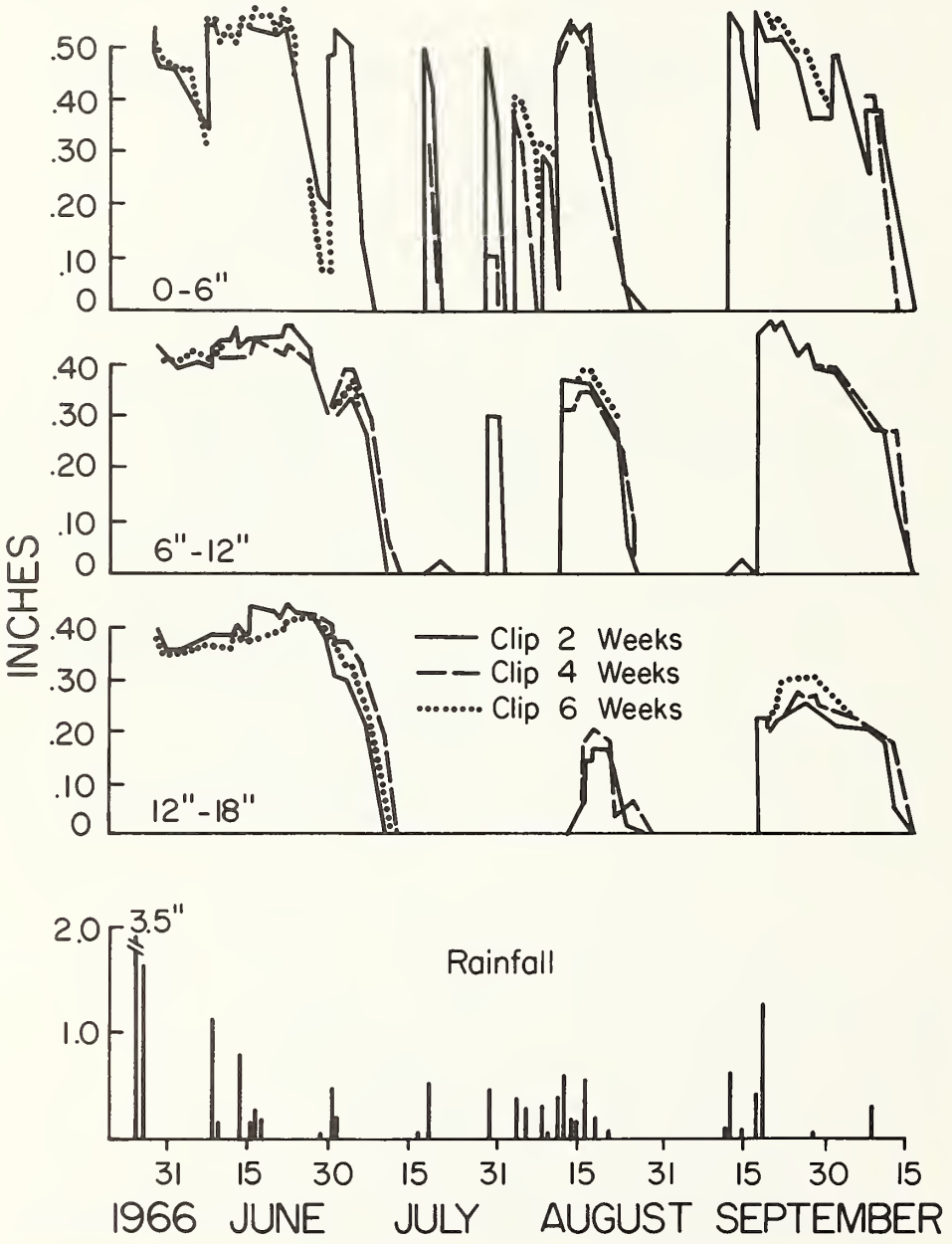

FIGURE 12.—Rainfall and soil-water content by days in 1966 under application of 200–100 lb nitrogen and potassium per acre.

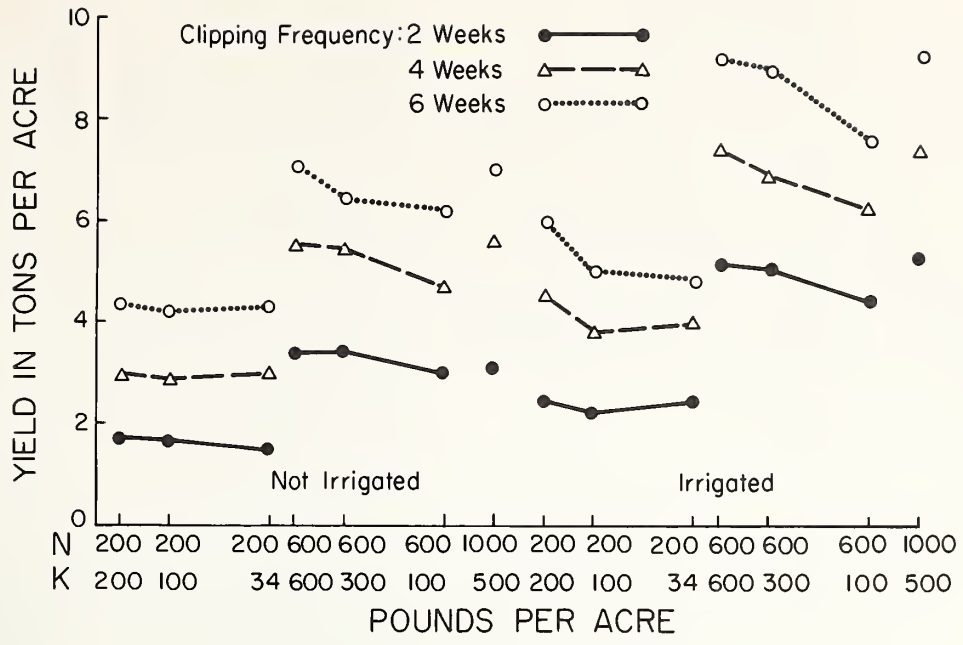

FIGURE 13.—Effect of irrigation, clipping frequency, and fertilizer level on yield of coastal bermudagrass.

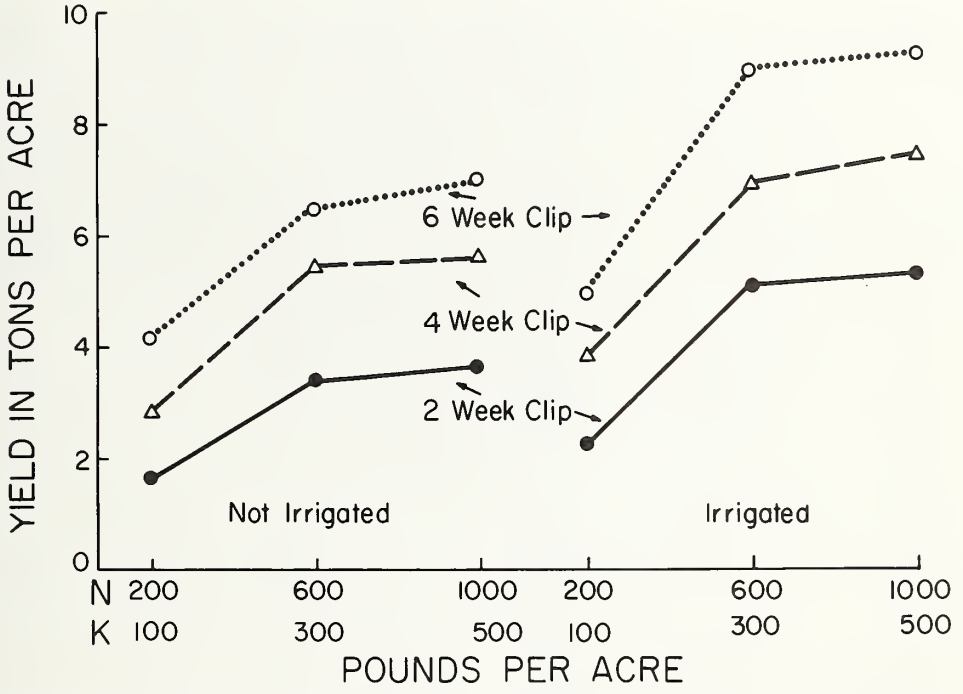

FIGURE 14.—Yield of coastal bermudagrass with the 2:1 nitrogen to potassium levels.

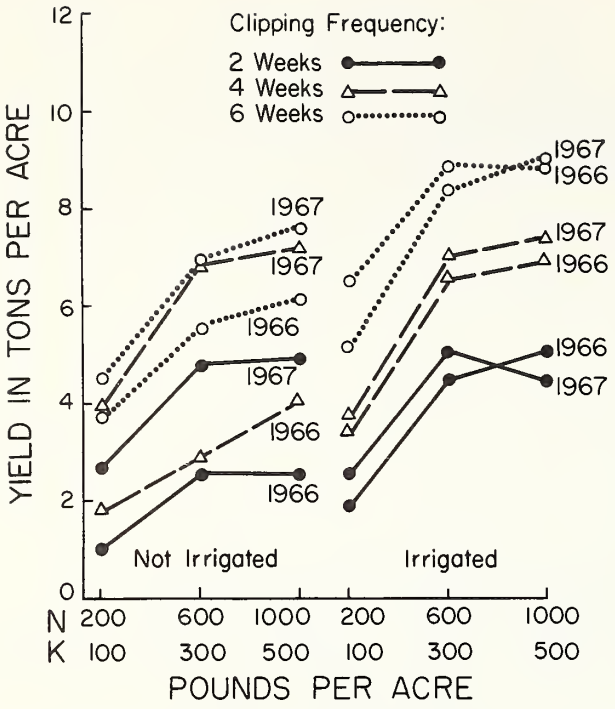

FIGURE 15.—Effect of nitrogen-potassium rate, clipping frequency, and water level on yield of coastal bermudagrass in a dry year (1966) versus a wet year (1967).

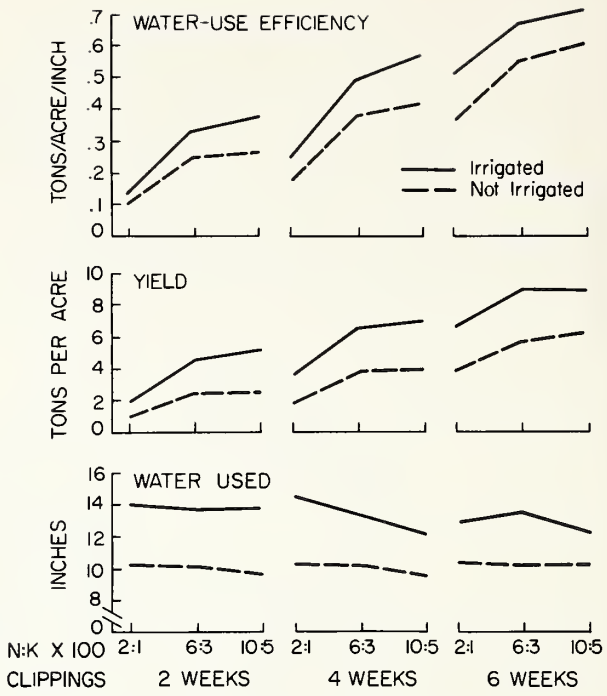

FIGURE 16.—Total water used, yield, and water-use efficiency of coastal bermudagrass in 1966, with three clipping frequencies and three levels of nitrogen and potassium fertilizer.

TABLE 21.—*Influence of soil-water and nitrogen levels, nitrogen-potassium ratios, and clipping frequency on coastal-bermudagrass forage production, 4-year average (1964–67)*

N-K ratio	Forage (tons/acre)					
	Irrigation			No irrigation		
	200 lb N/acre	600 lb N/acre	1,000 lb N/acre	200 lb N/acre	600 lb N/acre	1,000 lb N/acre
	2-week clipping interval					
1:1	2.47	5.19	...	1.71	3.47	...
2:1	2.26	5.09	5.27	1.67	3.45	3.68
6:1	2.47	4.46	...	1.50	3.03	...
Average	2.40	4.91	5.27	1.63	3.32	3.68
	4-week clipping interval					
1:1	4.55	7.40	...	3.02	5.56	...
2:1	3.88	6.91	7.36	2.91	5.51	5.67
6:1	4.05	6.25	...	3.04	4.79	...
Average	4.16	6.85	7.36	2.99	5.29	5.67
	6-week clipping interval					
1:1	6.01	9.14	...	4.34	7.09	...
2:1	5.03	8.91	9.18	4.20	6.48	7.01
6:1	4.84	7.55	...	4.30	6.21	...
Average	5.29	8.53	9.18	4.28	6.59	7.01

(*3*) *Yields.*—Forage yields were increased by irrigation at all fertility levels and clipping frequencies, by increased fertility on both water levels and all three clipping treatments, and by increased interval between clipping at all fertility and irrigation treatments (table 21). The 4-year average yields ranged from 1.50 tons per acre with 200–34 N–K, 2-week clipping, and no irrigation, to 9.18 tons per acre with 1,000–500 N–K, 6-week clipping, and irrigation. The N–K ratio had no effect on yield with the rate of 200 lb N/acre on all three clipping frequencies without irrigation and with irrigation on the 2-week clipping. Yields declined as the proportion of K decreased at the rate of 600 lb N/acre on all clipping frequencies with and without irrigation (fig. 14). There was only a small increase for the 1,000–500 N–K over the 600–300 N–K with and without irrigation and on all clipping frequencies (fig. 15). Yield responses with the 2:1 N–K ratio in 1966, a dry year, versus 1967, a wet year, showed that yields generally increased as N–K was increased both years with and without irrigation. Irrigation markedly increased yields in 1966 over 1967 for all clipping frequencies (fig. 16).

(*4*) *Water-use efficiency.*—Water-use efficiency (unit of forage produced per unit of water used) was related to both production of forage and amount of water used, with the production being the dominant factor. Irrigation, time between clipping, and fertility level all increased the efficiency of water use (fig. 13) because they increased yield. The use efficiency in tons per acre per inch of water used varied from 0.10 for not irrigated, 2-week clipping, and 200–100 N–K to 0.72 for irrigated, 6-week clipping, and 1,000–500 N–K. This sevenfold increase in production per unit of input illustrates how the selection of soil and water management practices can affect the efficiency of production.

Root Distribution

Coastal versus common bermudagrass

TREATMENTS.—Common and coastal bermudagrasses were established on Cecil sandy loam soil where prior soil tests indicated initial levels of 21 to 41 pounds per acre P_2O_5 and 100 to 200 pounds per acre K_2O. One ton of dolomitic limestone per acre was disked into the soil ahead of planting the grasses. Fertilizer variables with $N–P_2O_5–K_2O$ rates ranging in eight steps from 0–0–0 to 400–200–200 pounds per acre were superimposed in a split-plot arrangement on the grasses. Nitrogen was applied 37.5 percent in the spring, 37.5 percent after the first grass harvest, and 25 percent after the second grass harvest. Half the P and K was applied in October and the balance in the spring with the first N application. Forage yields were taken at intervals of 5 weeks for 3 years. Soil cores 4 inches in diameter were taken to a depth of 84 inches in October of the third year and placed in washing boxes. The boxes were agitated in water until all soil was removed. The roots were then dried and weighed by 6-inch increments of soil depth. Soil-water content was measured in the spring and again after the last grass harvest. Water-use rates were computed from the rainfall between the beginning of growth in the spring and the last grass harvest±the difference in soil-water content between these two measurements.

RESEARCH RESULTS.—Common bermudagrass fertilized with 400–200–200 lb $N–P_2O_5–K_2O$ per acre produced 30 percent more roots in the 0- to 6-inch horizon than did coastal bermudagrass treated in the same manner (table 22).

TABLE 22.—*Distribution and weight of roots of coastal and common bermudagrasses as affected by fertilizer*

[Pounds per acre]

Soil depth (inches)	Coastal bermudagrass		Common bermudagrass	
	0–0–0	[1]400–200–200	0–0–0	[1]400–200–200
0–6	1,156	2,618	1,619	4,140
6–12	347	892	300	679
12–18	288	770	342	419
18–24	263	635	253	272
24–30	271	771	250	343
30–36	502	710	294	211
36–42	275	205	168	34
42–48	125	66	266	4
48–54	60	32	60	8
54–60	17	17	19	0
60–66	42	42	26	2
66–72	78	47	8	0
72–78	16	29	1	0
78–84	0	24	0	0
Total	3,440	6,858	3,606	6,112

[1] Pounds per acre ($N–P_2O_5–K_2O$) applied annually.

The quantity of coastal-bermudagrass roots exceeded the amount of common-bermudagrass roots in the 6- to 12-inch and 12- to 18-inch zones. The quantity of coastal-bermudagrass roots was at least double that of common bermudagrass in all zones below 18 inches. The roots of coastal bermudagrass penetrated deeper and were more evenly distributed throughout the soil profile than the roots of common bermudagrass.

Fertilizer significantly increased the weight of coastal-bermudagrass roots to a depth of 3 feet, but the weight of common-bermudagrass roots to a depth of only 1 foot (table 22). Harvesting completely defoliated the plants, and the energy for initial regrowth came largely from stored root reserves. No significant differences at the 5-percent probability level were recorded in root distribution or the total amount of roots between coastal and common bermudagrasses without fertilizer. Adams et al. (*1*) showed that root penetration is an important factor in plant survival and growth during periods of moisture deficiency. Rooting depth of coastal and common bermudagrasses decreased as soil moisture increased. At the highest fertilizer level, common bermudagrass had 67.7 percent of its roots in the top 6 inches of soil. The amount of roots in the 6- to 12-inch, 12- to 18-inch, 18- to 24-inch, and 24- to 30-inch zones was 11, 7, 5, and 6 percent, respectively. Less than 1 percent of the roots of common bermudagrass were below 30 inches. Coastal bermudagrass, similarly treated, had 38.2 percent of its roots in the top 6 inches of soil. The amount of coastal-bermudagrass roots in the 6- to 12-inch, 12- to 18-inch, 18- to 24-inch, and 24- to 30-inch zones was 13, 11, 9, and 11 percent, respectively. Seventeen percent of the roots were below 30 inches.

Forage yields of coastal bermudagrass were higher than common bermudagrass at all fertility levels (fig. 17). Fertilizer influenced forage production of both bermudagrasses far more than it influenced root growth. The percentage of the total plant in the roots declined as the amount of fertilizer applied increased. The herbage to root ratio of coastal bermudagrass varied from 0.8:1 with no fertilizer to 2.2:1 at the highest fertilizer level. At the same time, the herbage to root ratio for common bermudagrass varied from 0.5:1 with no fertilizer to 1.6:1 at the highest fertilizer level. Roots, which compose about one-third of coastal-bermudagrass plants by weight, are capable of producing more than 7 tons of dry top growth per acre at the high fertilizer level.

The root fractions of the total coastal-bermudagrass plant for the lowest and highest fertilizer levels were 55 and 31 percent, respectively. For common bermudagrass, the percentages were 67 and 39 for the lowest and highest fertilizer levels, respectively.

Soil water used per ton of coastal-bermudagrass forage decreased rapidly as fertilizer levels increased. Soil water used ranged from 9.8 inches to 2.7 inches per ton of forage produced for the 0–0–0 and 400–200–200 fertilizer levels, respectively (fig. 17). Soil-moisture data collected indicated that no water moved below a depth of 4 feet during the growing season.

Common bermudagrass used about 50 percent more water than coastal bermudagrass to produce a ton of forage at all fertilizer levels. The water used per ton of common-bermudagrass forage also declined as fertilizer levels increased (fig. 17). Water required to produce a ton of forage ranged from 14.9 to 4.6 inches.

This study showed that an average of one forage harvest every 4 years can be expected

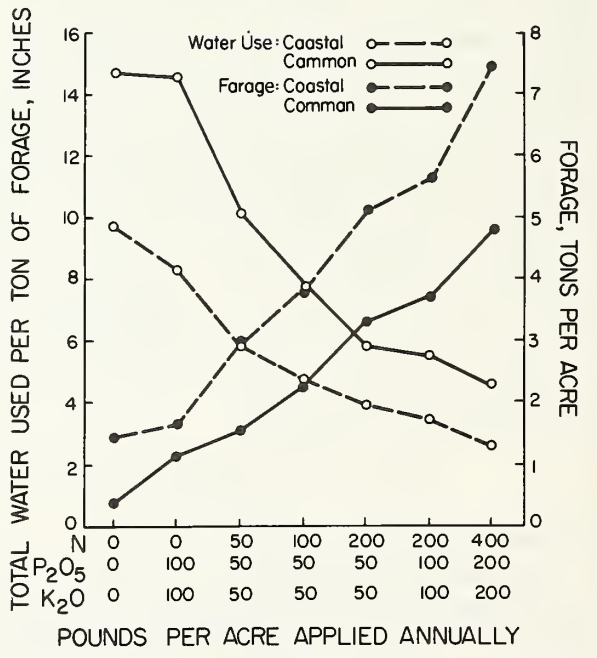
TOTAL WATER USED PER TON OF FORAGE, INCHES
FORAGE, TONS PER ACRE
Water Use: Coastal
Common
Forage: Coastal
Common
N 0 0 50 100 200 200 400
P2O5 0 100 50 50 50 100 200
K2O 0 100 50 50 50 100 200
POUNDS PER ACRE APPLIED ANNUALLY

FIGURE 17.—Forage production and water-use efficiency of coastal and common bermudagrasses at selected fertility levels, 1955–57.

to be lost because of dry weather. The greater quantity of coastal-bermudagrass roots below 30 inches in combination with greater root activity and vigorous growth on well-drained soil in Georgia account for its excellent acceptance and wide adaptation.

Effects of nitrogen-potassium level, clipping frequency, and irrigation on coastal bermudagrass

TREATMENTS.—Soil cores 4 inches in diameter were taken to 60 inches depth under coastal bermudagrass in the study of the N–K levels, clipping frequency, and water levels reported above. Cores were taken from the 200–100, 600–300, and 1,000–500 N–K levels on the 2-, 4-, and 6-week clipping frequency, irrigated treatments. Times of sampling were April, July, and October 1967, and February 1968, to represent the beginning, middle, and end of the growing season and the dormant season, respectively. Another set of samples was taken in July 1968 from the 1–1 and 6–1 N–K treatments on the three clipping frequencies with and without irrigation. The soil cores were divided into segments of 0–3, 3–6, 6–12, 12–18, 18–24, 24–36, and 36–60 inches for relating root growth to soil depth. All soil was washed from the roots, and the roots were ovendried and weighed in grams. Results reported in grams per plot can be converted to tons per acre with the conversion formula grams per core$\times$0.586=tons per acre.

RESEARCH RESULTS.—Data from the root samples taken in April, July, October, and February (table 23) show that a high percentage of the weight of roots was in the top 3 inches of the soil. However, some roots were below 5 feet at all seasons under all treatments (fig. 18). Root yields in winter were slightly lower than in the summer. Plots clipped at the 6-week interval had consistently higher root yields than the 4- or 2-week clipping-frequency plots. Differences in root yield between the 2- and 4-week clipping-frequency plots were small and not consistent at all samplings.

Root yields appeared to be decreased by increasing N–K levels at the 2-week clipping frequency. At the 4- and 6-week clipping frequencies the highest root yield was associated with the 600–300 N–K level, followed in order by the 1,000–500 and the 200–100 level, which was associated with the lowest root yield. The average effect of N–K level suggested a small, if real, influence of level of N–K fertilization on total root yield. The highest root yield

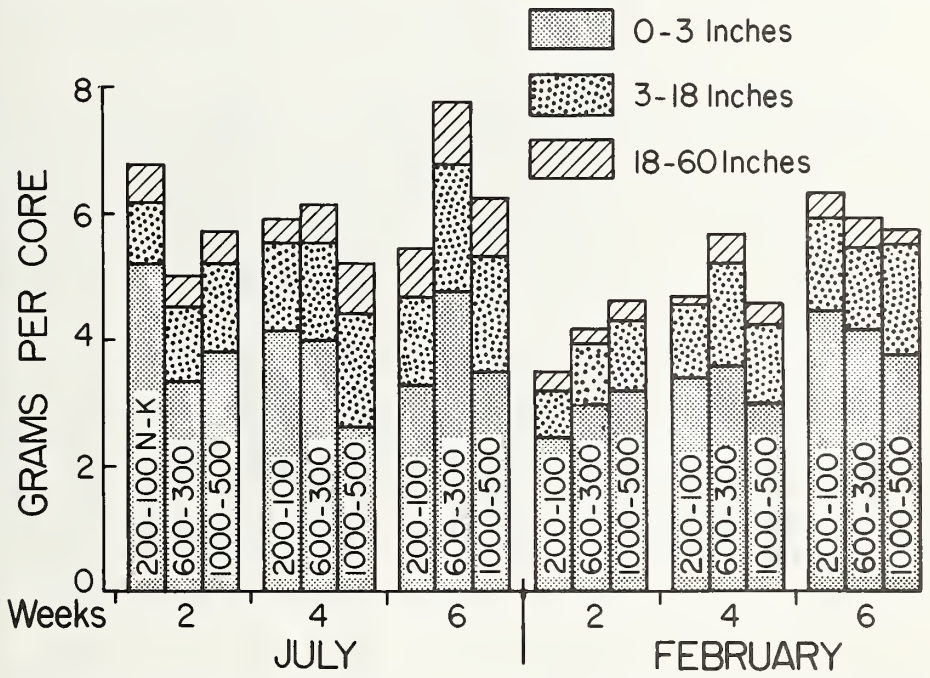

FIGURE 18.—Quantity of roots to 60 inches depth under coastal bermudagrass in July and February with three clipping frequencies and three nitrogen-potassium levels.

was associated with the 6-week clipping frequency and the medium N–K level, suggesting an interaction between frequent clipping and high N–K fertilization to produce lower total root weights.

The distribution of total roots with depth suggests that a smaller proportion exists in the 0- to 3-inch layer at increasing N–K levels. The 0- to 6-inch layer contained 80, 76, and 73 percent of the total root weight for the levels of 200–100, 600–300, and 1,000–500 N–K, respectively. Only 5.3, 6.6, and 5.2 percent of the total root weight was found in the 24- to 60-inch zone for each of three N–K levels, respectively. Of greater significance may be the observation that the 0- to 12-inch layer contained approximately 85 percent of the total root yield. (Practically 90 percent of the total roots were in the 0- to 18-inch layer.)

The 2-week clipping-frequency treatment had proportionately more roots in the 0- to 3-inch layer than the 4- or 6-week clipping-frequency

TABLE 23.—*Average root yields as affected by soil horizon, clipping frequency, and nitrogen-potassium levels*

Soil horizon (inches)	Root yields (g/core)[1] at rate of nitrogen-potassium applied (lb/acre)								
	2-wk clipping interval			4-wk clipping interval			6-wk clipping interval		
	200–100	600–300	1,000–500	200–100	600–300	1,000–500	200–100	600–300	1,000–500
	April sampling								
0–3	3.70	4.46	3.22	3.28	3.95	2.62	4.34	5.08	4.87
3–6	.20	.26	.30	.25	.28	.33	.46	.44	.62
6–12	.11	.28	.35	.27	.37	.65	.43	.55	.59
12–18	.07	.25	.21	.19	.26	.41	.25	.35	.39
18–24	.08	.21	.14	.19	.17	.29	.21	.25	.19
24–36	.22	.15	.19	.29	.16	.51	.38	.54	.15
36–60	.08	.06	.04	.05	.05	.07	.08	.39	.02
Total	4.46	5.67	4.45	4.52	5.24	4.88	6.15	7.60	6.83
	July sampling								
0–3	4.96	3.36	3.82	4.11	3.97	2.63	3.27	4.75	3.48
3–6	.43	.31	.51	.62	.57	.47	.49	.61	.53
6–12	.46	.48	.54	.51	.60	.74	.51	.81	.72
12–18	.34	.37	.35	.31	.41	.57	.39	.60	.59
18–24	.16	.20	.19	.26	.22	.39	.28	.37	.34
24–36	.38	.26	.15	.08	.31	.41	.39	.41	.43
36–60	.05	.08	.16	.01	.04	.02	.12	.21	.16
Total	6.78	5.06	5.72	5.90	6.12	5.23	5.45	7.76	6.25
	October sampling								
0–3	4.36	3.71	2.77	3.54	3.00	4.42	4.18	3.47	3.88
3–6	.26	.30	.24	.41	.40	.50	.44	.30	.44
6–12	.38	.30	.39	.33	.41	.52	.43	.37	.46
12–18	.22	.21	.22	.13	.30	.45	.31	.21	.29
18–24	.14	.15	.09	.08	.20	.29	.26	.14	.17
24–36	.19	.27	.14	.06	.33	.14	.31	.25	.23
36–60	.02	.22	.02	.02	.11	.02	.25	.03	.06
Total	5.57	5.16	3.87	4.57	4.75	6.34	6.18	4.77	5.53
	February sampling								
0–3	2.43	2.99	3.15	3.38	4.16	2.95	4.43	4.13	3.73
3–6	.30	.33	.42	.39	.39	.52	.78	.50	.57
6–12	.31	.39	.45	.48	.36	.46	.43	.52	.67
12–18	.15	.22	.28	.29	.28	.31	.26	.26	.47
18–24	.09	.11	.17	.08	.23	.16	.21	.20	.15
24–36	.13	.09	.10	.04	.20	.17	.16	.25	.08
36–60	.07	.05	.02	.02	.06	.01	.02	.07	.03
Total	3.48	4.18	4.59	4.68	5.68	4.58	6.29	5.93	5.70

[1] Grams/core × 0.586 = tons/acre.

treatment. The percentages of total roots below 18 inches tended to increase with increasing length of clipping interval (8.3, 9.2, and 10.4 percent of the total for the 2-, 4-, and 6-week clipping frequencies, respectively). Whether these differences have biological or statistical significance is not known.

Seasons do not appear to affect the root weights in the 0- to 3-inch layer. There appears to be more of the total root weight below 6 inches in the midsummer sampling than in the fall, spring, or winter sampling (22.2, 28.5, 21.6, and 21.3 percent of the total root weight during spring, summer, fall, and winter, respectively).

Data from the root samples taken in the summer of 1968 show that yields of coastal-bermudagrass roots in the 0- to 3-inch layer were consistently higher in the unirrigated treatments, regardless of N–K level or clipping frequency (table 24). The average root yields for the 2-, 4-, and 6-week clipping frequencies in the irrigated treatments were 6.1, 4.8, and 6.2 g/core, respectively. The corresponding root yields for the no irrigation treatments were 8.3, 8.1, and 8.6 g/core. The increase in average total root yield for the unirrigated treatments over the irrigated treatments for the 2-, 4-, and 6-week clipping frequencies was 37, 70, and 39 percent, respectively. A low level of potassium appeared to reduce root yield. Generally, root yields were lower at the 6:1 N–K ratio than the 1:1 ratio except at 6 weeks under no irrigation (fig. 19).

The distribution of total roots with depth suggests that a smaller proportion exists in the 0- to 3-inch layer at increasing N–K levels for both the irrigated and the unirrigated treatments (table 24). The average root yields indicate the unirrigated treatments had a higher percentage of roots in the 0- to 3-inch zone and below 2 feet than the irrigated treatments. There was a higher percentage of roots in the 3- to 24-inch zone for the irrigated treatments.

The 2-week clipping-frequency treatment had proportionately more roots in the 0- to 3-inch layer than the 4- or 6-week clipping-frequency treatments for both the irrigated and unirrigated treatments. The proportion of roots in the 0- to 3-inch zone between soil-water levels increased as the clipping frequency widened from 2 to 4 to 6 weeks. The unirrigated treatment had more roots in the 0- to 3-inch zone and the 24- to 60-inch zone, and the irrigated

TABLE 24.—*Average yields of coastal-bermudagrass roots as affected by soil horizon, clipping frequency, nitrogen-potassium levels, and irrigation, summer 1968*

Soil horizon (inches)	Root yields (g/core)[1] at rate of nitrogen-potassium applied (lb/acre)											
	2-wk clipping interval				4-wk clipping interval				6-wk clipping interval			
	200–200	200–33	600–600	600–100	200–200	200–33	600–600	600–100	200–200	200–33	600–600	600–100
	Irrigation											
0–3	4.80	5.43	4.68	2.95	5.04	2.88	2.99	1.92	4.60	1.98	5.45	3.68
3–6	.45	.34	.53	.48	.55	.48	.52	.46	.88	.46	.69	.55
6–12	.37	.37	.48	.43	.43	.55	.58	.37	.62	.45	.90	.59
12–18	.23	.26	.32	.28	.26	.21	.44	.35	.45	.23	.45	.52
18–24	.11	.29	.25	.25	.16	.11	.17	.15	.23	.08	.30	.23
24–36	.06	.22	.24	.22	.19	.08	.12	.08	.33	.09	.44	.28
36–60	.02	.04	.14	.04	.11	.01	.05	.02	.09	.02	.06	.12
Total	6.03	6.94	6.65	4.65	6.74	4.32	4.87	3.35	7.20	3.30	8.28	5.96
	No irrigation											
0–3	8.13	5.49	6.28	4.79	6.87	3.88	5.89	5.86	5.86	5.25	4.86	7.40
3–6	.61	.56	.62	.50	.86	.36	.64	.66	.53	.55	.45	.82
6–12	.39	.53	.66	.54	.52	.36	.82	.62	.76	.54	.55	.98
12–18	.34	.34	.31	.23	.41	.29	.49	.44	.43	.44	.34	.80
18–24	.23	.17	.23	.21	.37	.20	.31	.28	.34	.29	.28	.42
24–36	.44	.34	.30	.36	.47	.24	.38	.33	.43	.41	.45	.58
36–60	.22	.10	.60	.22	.30	.28	.18	.10	.31	.07	.06	.15
Total	10.36	7.54	8.46	6.86	9.80	5.61	8.71	8.25	8.67	7.54	7.03	11.15

[1] Grams/core × 0.586 = tons/acre.

TABLE 25.—*Average root yields of coastal bermudagrass and alfalfa as influenced by lime sources, rates, and soil horizon*

[Grams per core][1]

Soil horizon (inches)	Dolomitic lime (tons/acre)				Calcitic lime (tons/acre)			
	0	3	9	Average	0	3	9	Average
	Coastal bermudagrass							
0–3	6.70	4.38	4.19	5.09	6.70	5.70	3.97	5.46
3–6	.57	.43	.47	.49	.57	.59	.47	.55
6–12	1.21	.66	.79	.89	1.21	.74	.63	.86
12–18	1.10	.52	.61	.74	1.10	.70	.68	.83
18–24	.87	.45	.33	.55	.87	.31	.27	.49
24–36	.30	.28	.42	.33	.30	.23	.25	.26
36–60	.09	.10	.13	.11	.09	.07	.19	.12
Total	10.84	6.82	6.94	...	10.84	8.35	6.47	...
	Alfalfa							
0–3	4.14	5.85	4.91	4.97	4.14	5.95	5.22	5.11
3–6	.76	1.75	1.35	1.29	.76	1.91	1.92	1.53
6–12	1.93	1.44	2.03	1.80	1.93	2.10	2.05	2.03
12–18	.67	.71	1.36	.91	.67	1.05	.82	.84
18–24	.23	.22	.20	.22	.23	.39	.12	.25
24–36	.08	.05	.04	.05	.08	.84	.13	.35
36–60	.00	.01	.00	.00	.00	.01	.01	.01
Total	7.81	10.02	9.89	...	7.81	12.24	10.28	...

[1] Grams/core×0.586=tons/acre.

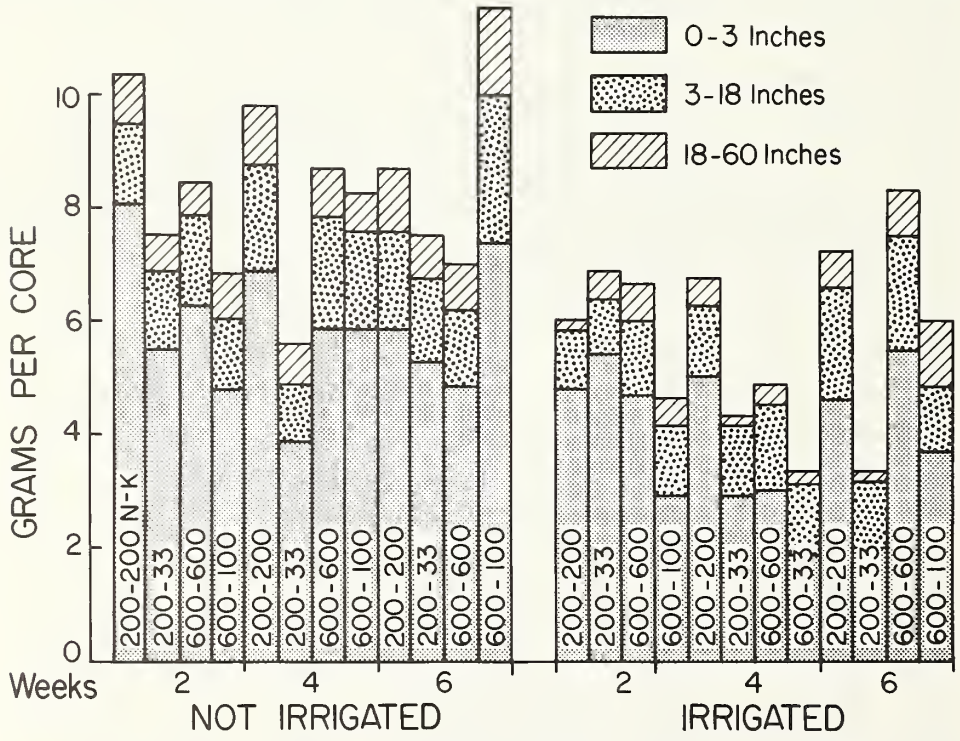

FIGURE 19.—Quantity of roots to 60 inches depth under coastal bermudagrass with and without irrigation, clipped at 2-, 4-, and 6-week intervals, with four levels of nitrogen-potassium fertilizer.

treatments had more roots in the intermediate zones.

Coastal bermudagrass versus alfalfa

TREATMENTS.—Root samples were taken in previous years from alfalfa and from coastal bermudagrass in the lime study reported in the next section. Treatments on the alfalfa and coastal bermudagrass included rates of 0, 3, and 9 tons dolomitic and calcitic limestone per acre. Root-sampling procedure was similar to that described in the preceding section.

RESEARCH RESULTS.—Coastal bermudagrass, which has a relatively low lime requirement, had more total roots in the 0-lime treatments, and the yield of alfalfa roots was higher than that of coastal bermudagrass at all other lime rates and sources studied. Alfalfa stands were poor on the 0-lime treatment. Except with the 0-lime treatment, alfalfa had more roots in the 0- to 3-inch zone, but coastal bermudagrass generally had more root weight than did alfalfa in the 18- to 60-inch zone (table 25 and fig. 20). Lime source appeared to affect the total root yield of alfalfa to a greater extent than that of coastal bermudagrass. Root yields of alfalfa were consistently higher on the calcitic lime treatments, and root yields of coastal bermudagrass were erratic with respect to source.

Influence of Lime Sources and Rates on Production of Coastal Bermudagrass, Soil-Profile Reaction, and Exchangeable Calcium and Magnesium in the Soil

TREATMENTS.—A field experiment, designed as a part of a regional lime study, was initiated in April 1957 on Cecil sandy loam. The exchange capacity of this soil ranged from 3.18 meq/100 g in the 0- to 6-inch depth to 4.86 at a depth of 24 to 30 inches, and soil pH ranged from 5.8 to 5.1 for the same depths.

The variables consisted of calcitic and dolomitic lime surface applied or mixed in the 0- to 6-inch depth. Rates of 0, 1.5, 3, 6, and 9 tons per acre were applied initially. One additional treatment received 3 tons per acre initially and was relimed annually according to soil tests, beginning in 1959, to maintain a soil pH near 6.5. The experimental design was a randomized complete block with four replications.

The neutralizing values of the calcitic and

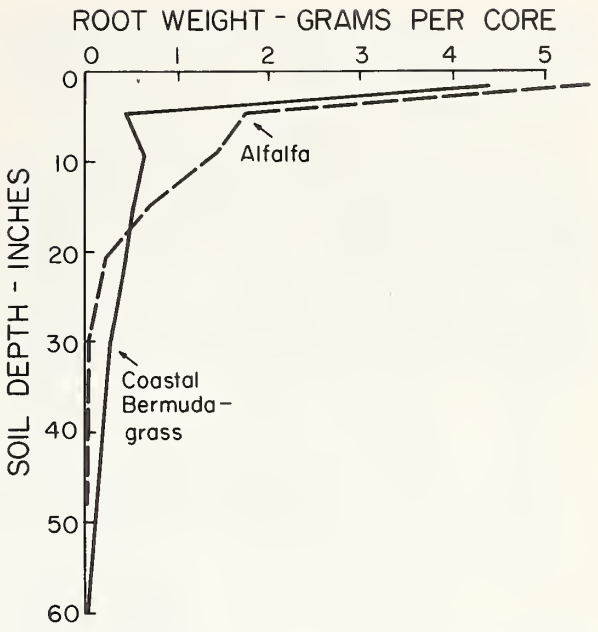

FIGURE 20.—Relative weights of coastal bermudagrass and alfalfa roots by soil depth (3 tons dolomitic limestone per acre).

dolomitic limestone were 98.8 and 100.8 percent, respectively. Screening tests showed that 91.2 percent of the calcitic and 93.4 percent of the dolomitic lime passed a 10-mesh sieve. The percentages of the calcitic and dolomitic lime finer than 80 mesh were 32.8 and 44.0, respectively.

Initial fertilization for establishing coastal bermudagrass in the spring of 1957 consisted of 250 and 487 lb P_2O_5 and K_2O per acre respectively, plowed and disked into the soil. Annual maintenance fertilization consisted of 100 and 200 lb P_2O_5 and K_2O per acre with half applied about April 1 and half applied after the second forage harvest. Initial N fertilization in 1957 consisted of 200 lb N/acre as NH_4NO_3 for establishment. Annual N fertilization beginning in 1958 was 800 lb N/acre as NH_4NO_3 in four applications: April 1 and after the first, second, and third harvests. Plots were irrigated immediately after the N application and as needed to maintain the soil-moisture suction in the 0- to 24-inch depth of soil at less than 2 bars. Soil moisture was monitored with a neutron probe. Beginning in 1959, 800 lb lime/acre was applied to the relimed plots (6.7 RE) after each N application, or four times each year. Including the initial application, these plots received a total of 11 tons per acre of lime during this study.

Coastal bermudagrass was harvested about

every 4½ weeks, except during the late summer when the clipping interval was extended. Forage yields were recorded as ovendry weights for 1959 to 1963. The data were analyzed according to Duncan's multiple-range test.

Soil samples were taken initially in May 1957 by compositing eight borings per plot for each 6-inch zone to a depth of 36 inches. In October 1963, 6.5 years later, plots were sampled in the same manner to a depth of 48 inches. All samples were air-dried and passed through a 20-mesh sieve. Soil-acidity measurements were made on a 1:1 soil-water suspension. Ammonium acetate-exchangeable Ca and Mg were determined by the EDTA method (*8*).

RESEARCH RESULTS.—No significant difference existed between lime treatments in coastal-bermudagrass production during the first 2 years of the study. However, yield differences tended to increase with time and significant yield differences between lime treatments were measured during the last 5-year period (1959 to 1963) of the study (table 26). During the last year of the study (1963), the range in

TABLE 26.—*Influence of lime rates and sources on soil pH (0 to 6 inches) and forage production of coastal bermudagrass, 1959–63*[1]

Initial lime rates (tons/acre)	Calcitic lime		Dolomitic lime		Average for carriers	
	Forage, 1959–63 (tons/acre)	1963 soil pH[2]	Forage, 1959–63 (tons/acre)	1963 soil pH[2]	1963 forage (tons/acre)	1963 soil pH[2]
0	7.39a	4.4	7.39a	4.3	8.04a	4.3
1.5	7.55b	4.5	7.61b	4.5	8.29b	4.5
3	7.66b	4.6	7.62b	4.5	8.40b	4.5
6	7.90c	4.8	7.77c	4.8	8.75c	4.8
9	7.99c	5.7	7.80c	5.2	8.68c	5.4
3RE[3]	7.82c	6.2	7.79c	5.5	8.64c	5.8

[1] Values in a column followed by the same letter are not significantly different at the 5% level.

[2] Soil was sampled in October 1963.

[3] RE = relimed annually, beginning in 1959, to maintain a soil pH near 6.5. Total of 27.2 tons applied in 7 years.

TABLE 27.—*Influence of lime sources and rates applied to coastal bermudagrass on soil-profile acidity (pH)*

[Soil pH][1]

Soil depth (inches)	Initial soil reaction, May 1957	Calcitic lime (tons/acre)[2]				Dolomitic lime (tons/acre)[2]			
		0	3	9	3RE[3]	0	3	9	3RE[3]
0–6	5.8	4.4	4.6	5.7	6.2	4.3	4.5	5.2	5.5
6–12	5.5	4.3	4.7	5.7	5.7	4.3	4.4	5.3	5.1
12–18	5.3	4.7	5.3	6.2	6.1	4.7	5.1	5.7	5.6
18–24	5.2	5.1	5.7	6.1	6.0	5.2	5.6	5.8	5.5
24–30	5.1	5.2	5.4	5.8	5.7	5.2	5.3	5.4	5.3
30–36	5.0	4.8	4.9	5.3	4.2	4.9	4.9	4.8	4.8
36–42	...	4.7	4.6	4.7	4.9	4.7	4.6	4.6	4.6
42–48	...	4.6	4.5	4.5	4.7	4.5	4.5	4.5	4.5

[1] Soil was sampled in October 1963.

[2] Each entry is an average of 8 plots.

[3] RE = relimed annually, beginning in 1959, to maintain a soil pH near 6.5. Total of 27.2 tons applied in 7 years.

forage production was from 8.04 tons per acre for the no-lime treatment to 8.75 tons per acre for the treatment of 6 tons per acre.

No significant difference occurred in forage production between the calcitic and dolomitic sources of lime. The same was true for lime placement, that is, surface application versus mixing the lime with the surface 6 inches of soil.

Coastal bermudagrass is tolerant to a wide range of soil pH. Table 26 shows no significant yield differences when the 1963 topsoil pH values ranged from 4.8 to 6.2.

The lime rate of 9 tons per acre produced the highest 5-year-average yield of coastal bermudagrass (table 26). The yields for the 3 tons per acre relimed treatment, which received a total of 11 tons per acre during this study, were slightly but not significantly lower. Both of these rates would usually be considered excessive for this sandy loam soil. However, the results from this study indicate that with high rates of acid N fertilizer, there is little danger of overliming this soil. A total of 4,900 lb N/acre as NH_4NO_3 was applied during the course of this study.

Soil pH in the surface 6 inches on the unlimed plots dropped from an initial pH of 5.8 to a pH of 4.4 at the end of the study (table 27). The influence of the acid-forming fertilizers was found in the 12- to 18-inch zone, where the soil reaction was reduced 0.6 pH unit below the initial level (5.3 to 4.7). During the same period, exchangeable Ca and Mg decreased markedly throughout the top 18 inches of soil (table 28). Soil pH was unaffected below 18 inches in the unlimed treatments.

The 3 tons per acre of lime applied in 1957 improved the soil reaction in the 18- to 24-inch zone over the initial soil reaction (table 27). However, this rate was not sufficient to prevent a decrease in soil reaction in the surface 12 inches of the soil profile. Both treatments of 9 tons per acre and 3 tons per acre relimed prevented any pronounced decrease in soil pH in the upper soil-profile layers and increased the soil pH in the 12- to 30-inch zone. At these high liming rates, calcitic and dolomitic limestone increased soil-pH values to the 36- and 30-inch depths, respectively. Table 28 shows that considerable movement of Ca and Mg occurred in the profile. Where no lime was applied, there was a net loss of exchangeable

TABLE 28.—*Influence of lime sources and rates on exchangeable calcium and magnesium, 1957 and 1963*

[Milliequivalents per 100 grams]

Soil depth (inches)	Initial, 1957, no lime	1963		
		No lime	Dolomitic, 9 tons/acre	Calcitic, 9 tons/acre
	Calcium[1]			
0–6	1.22	0.15	1.06	2.42
6–12	1.65	.15	1.09	2.01
12–18	1.66	.78	1.29	2.19
18–24	.95	1.33	1.40	1.75
24–30	.39	1.37	1.40	1.51
30–36	.16	.66	.78	1.37
Mean	1.00	0.74	1.17	1.87
	Magnesium[2]			
0–6	0.31	0.15	0.37	0.15
6–12	.40	.18	.50	.17
12–18	.53	.14	.68	.19
18–24	.72	.33	.55	.15
24–30	.63	.46	.48	.25
30–36	.50	.41	.36	.41
Mean	0.51	0.27	0.49	0.22

[1] 1 meq Ca/100 g of soil is equivalent to 200 parts per million Ca, or 400 lb Ca/acre.

[2] 1 meq Mg/100 g of soil is equivalent to 122 parts per million Mg, or 244 lb Mg/acre.

Ca and Mg from the total soil profile between 1957 and 1963. Decreases from initial levels of both Ca and Mg were greatest in the top 18 inches of the soil profile. Exchangeable Mg levels decreased at all soil depths; however, Ca levels increased in the 18- to 36-inch zone.

Ca and Mg depletion from the soil profile was largely prevented where 9 tons dolomitic limestone per acre was applied. Even though exchangeable Ca levels, as compared with initial levels, were slightly lower in the surface 18 inches of the profile, the net content for the entire profile showed a slight gain. Over the same period, soil-profile-Mg content was essentially unchanged.

Where calcitic limestone was applied, content of soil-profile Mg decreased to levels corresponding to those of the unlimed treatments. However, the exchangeable Ca levels throughout the soil profile were higher with calcitic than with dolomitic limestone. These gains represented increases over the initial Ca levels in every soil zone. As was pointed out previously, this source also had a greater effect in increasing soil pH.

The greater effectiveness of the calcitic limestone as compared with the dolomitic in raising soil pH and Ca levels does not necessarily indicate that this source is always preferable to the dolomitic source. The lack of Mg, an important nutrient that could become deficient under high fertilization and leaching conditions, would make dolomitic limestone a more desirable material. Calcitic limestone probably should be the preferred liming material where problems with soil-profile acidity are critical and where quicker corrective measures are desired.

The results of this study indicate that the development of soil-profile acidity under conditions of high fertilization with residually acidic N fertilizers can be prevented by using lime rates of 9 to 11 tons per acre. Although these rates are generally considered excessive for Cecil soil, they were found to be necessary under these conditions to prevent depletions of Ca and Mg and the development of soil acidity in the soil profile.

Influence of Limestone and Nitrogen on Soil pH and Yield of Coastal Bermudagrass

TREATMENTS.—A study was initiated in 1958 to determine the response of top and root growth of coastal bermudagrass to various combinations of nitrogen and limestone and the rate of movement of bases into the subsoil of an initially very acidic soil.

The soil was a Cecil sandy loam having 8 to 10 inches of A horizon, a high level of available P and K, and a pH ranging from 5.7 in the surface soil to 5.4 in the 12- to 36-inch zone. Since the pH range was not below the levels expected to reduce growth of the test crop, it was necessary to artificially increase soil acidity throughout the profile. This increase was achieved by surface application of 2,000 lb/acre each of ammonium sulfate and ammonium nitrate at approximately 4-week intervals during the summer and fall of 1958. A total of 10,000 lb N fertilizer per acre was applied before initiating the treatment variables. Most of the excess N was leached out by irrigation and winter rains.

Treatments applied in April 1959 included all combinations of five rates of N as NH_4NO_3, three rates of dolomitic limestone, and two placements of the limestone as shown in table 29. The neutralizing value of the limestone was 100.8 percent. Screening tests showed that 93.4 percent of the limestone passed a 10-mesh sieve and that 44 percent was finer than 80-mesh.

Nitrogen was applied as NH_4NO_3 at designated rates in four equal applications on April 1, and following the first, second, and third harvest.

The lowest rate of limestone used was calculated to neutralize the 0- to 6-inch zone and the higher rate the 0- to 24-inch zone. Calculations were based on the fraction of the limestone that would pass a 40-mesh screen. In addition, a uniform application of 500 lb limestone/acre was made to assure a well-established stand of the test crop. The entire plot area was rototilled, after which limestone was broadcast on plots designated to receive surface applications. The 0- to 6-inch layer was then removed from the other plots, thoroughly mixed with limestone and replaced, and coastal bermudagrass was planted. The grass became fully established in 1960, and collection of yield data began in 1961.

The experimental design was a randomized complete block with five replications, using 30- by 30-inch plots with 6-inch-deep metal borders extending 4 inches below the soil surface.

Phosphorus and potassium rates were based on the N rate, so that a 2:1:1 ($N–P_2O_5–K_2O$) ratio was used on all treatments. The P was applied annually in April and the K in four equal amounts at the same time as the N.

Soil water was maintained at less than 2 bars average suction in the 0- to 24-inch zone. Each irrigation was sufficient to bring the soil to field capacity to a depth of 6 feet.

Soil samples were taken by 6-inch zones to 48 inches initially and annually thereafter following the last grass harvest in October. The samples were air-dried, ground through a 20-mesh screen, and mixed before analysis.

Coastal-bermudagrass forage was harvested at approximately 42-day intervals. The data were analyzed according to Duncan's multiple-range test.

Roots were recovered by washing from soil cores taken with a soil sampler. Three cores were taken in each plot of one replication after the last grass harvest in October 1963.

Soil reaction was measured with a glass electrode pH meter using a 1:1 soil-water suspension. Exchangeable Ca and Mg were determined

in a 1*N* ammonium acetate extract by atomic-absorption spectroscopy.

RESEARCH RESULTS.—Subsoil-acidity levels created by the initial, extremely heavy applications of N are indicated by the low pH values of the 0-limestone, 0–N treatment in table 29. The pH values of the initial (1960) samples were no different from those of the 0-limestone, 0–N plots sampled at the end of the experiment and are not included. The pH values ranged from 4.3 to 4.7 in the 6- to 48-inch profile. During the 3½-year cropping period, annual applications of N without limestone further reduced soil pH, the depths affected depending upon the rate of N application. The rate of 200 lb N/acre reduced the pH of only the 0- to 6-inch soil layer, but the rate of 1,600 lb/acre reduced subsoil pH to the 48-inch depth (table 29).

The application of limestone at either the 3.5 or 18 tons per acre rate, mixed or surface-applied, prevented reduction of subsoil pH except where N rates were 800 lb/acre or more.

Surface-applied limestone had not increased soil pH appreciably below the 6-inch depth at either the rate of 3.5 or the rate of 18 tons per acre after 3½ years, and the lower rate was insufficient to compensate residual acidity of any but the lowest N application. The lower pH values in the 0- to 6-inch zone for the surface-applied limestone, when compared with the corresponding mixed treatment, are due to the mixed limestone being in contact with a larger volume of soil and more rapid neutralization of the acidity. When the limestone was mixed in the 0- to 6-inch zone, soil pH was increased only to the 12-inch depth at the rates of 0 nitrogen and 200 lb N/acre. At intermediate rates of N, the effect extended to the 18- to 24-inch zone.

One explanation of this effect is that deeper incorporation of limestone produces a better opportunity for the products of nitrification to react with the limestone to form mobile $Ca(NO_3)_2$. At higher rates of N, there would be $Ca(NO_3)_2$ present in excess of plant uptake from the surface soil free to move downward in the profile. Subsequent differential absorption of NO_3, denitrification or leaching, would leave Ca ions to increase exchangeable bases.

TABLE 29.—*Soil-profile acidity as influenced by rates and placement of limestone and by nitrogen levels applied to coastal bermudagrass, October 1963*[1]

Soil depth (inches)	Soil pH[2] at rate of nitrogen applied (lb/acre) with—														
	No limestone					Dolomitic limestone									
						Surface-applied					Mixed, 0–6 inches				
	0	200	400	800	1,600	0	200	400	800	1,600	0	200	400	800	1,600
						3.5 tons limestone per acre									
0–6	5.3*	4.7*	4.7	4.5	4.2	5.9*	5.3*	4.9*	4.9	4.3	6.2	5.6	5.4	4.8	4.5
6–12	4.7	4.6	4.3*	4.1	4.0	4.8	4.8	4.7	4.2*	3.9	5.1*	5.3*	5.3	4.6	4.0
12–18	4.5	4.6	4.5	4.1	4.0	4.5	4.6	4.6	4.5	4.2	4.5	4.7	4.7*	4.7	4.2
18–24	4.4	4.4	4.4	4.3*	4.0	4.4	4.4	4.4	4.4	4.2	4.4	4.3	4.5	4.6*	4.3
24–30	4.3	4.3	4.3	4.3	4.0	4.3	4.3	4.3	4.3	4.1	4.3	4.3	4.4	4.4	4.4
30–36	4.3	4.3	4.4	4.3	4.1	4.3	4.5	4.3	4.4	4.2	4.4	4.4	4.4	4.3	4.3
36–42	4.4	4.5	4.5	4.4	4.2	4.5	4.6	4.4	4.4	4.2	4.5	4.6	4.4	4.4	4.3
42–48	4.7	4.6	4.6	4.6	4.3*	4.7	4.7	4.6	4.5	4.3*	4.6	4.7	4.5	4.5	4.3*
						18 tons limestone per acre									
0–6	...	...	...	...	...	6.3*	5.8*	5.5*	5.3	5.1	7.0	6.8	6.4	5.8	5.4
6–12	...	...	...	...	...	4.9	4.9	4.8	4.5*	4.1	6.2	6.3	6.4	6.1	4.9
12–18	...	...	...	...	...	4.7	4.6	4.7	4.6	4.2	4.7*	4.8*	5.1*	5.5	5.1
18–24	...	...	...	...	...	4.4	4.4	4.5	4.6	4.3	4.4	4.4	4.4	4.7*	4.6
24–30	...	...	...	...	...	4.3	4.3	4.3	4.4	4.2	4.3	4.3	4.3	4.4	4.4
30–36	...	...	...	...	...	4.5	4.3	4.4	4.3	4.3	4.3	4.4	4.4	4.3	4.3
36–42	...	...	...	...	...	4.6	4.5	4.5	4.4	4.3	4.3	4.4	4.5	4.4	4.5
42–48	...	...	...	...	...	4.7	4.7	4.6	4.6	4.4*	4.7	4.5	4.6	4.5	4.4*

[1] Initial applications of nitrogen and limestone were made in 1958.

[2] Values within a treatment followed by an asterisk denote a change in pH as compared to the treatment of no limestone and no nitrogen.

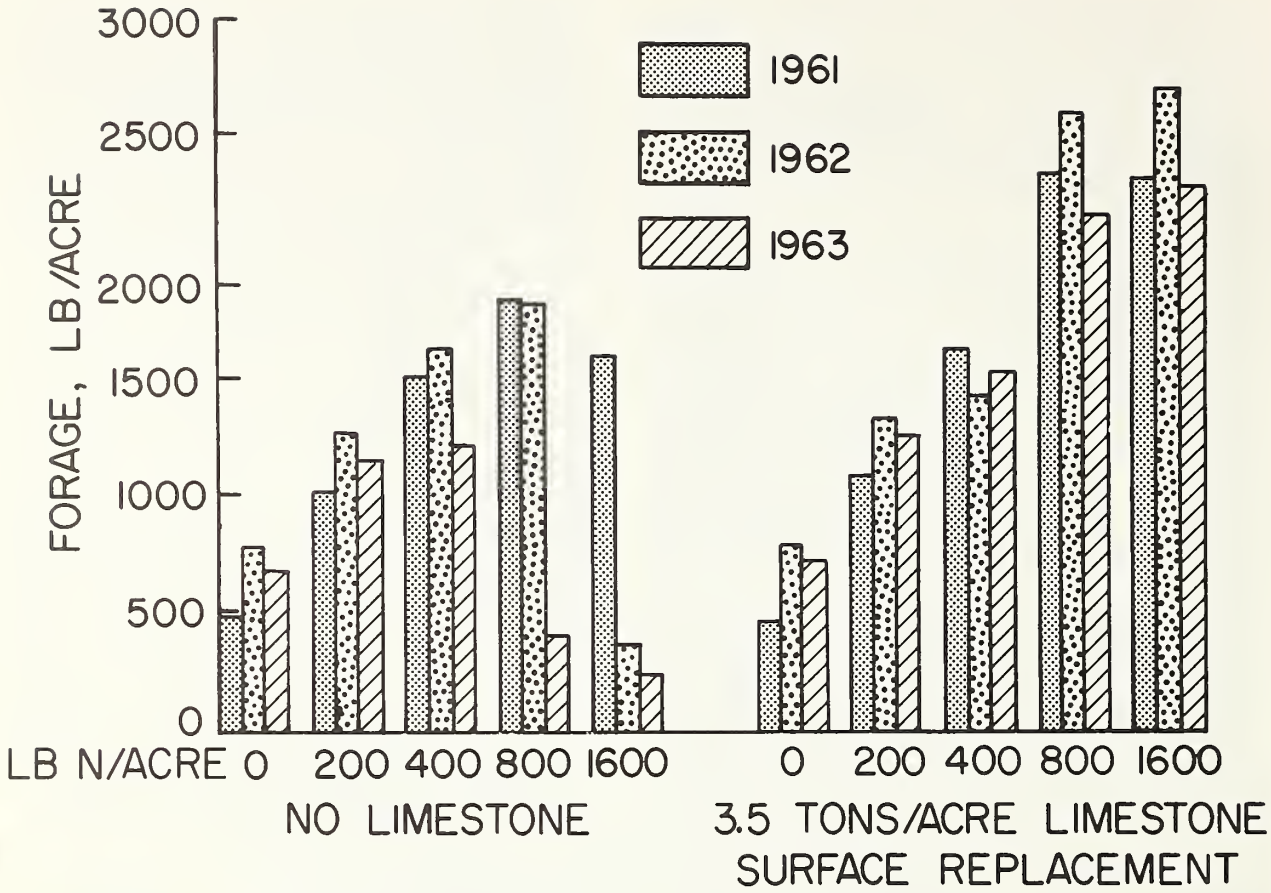

FIGURE 21.—Annual trends in the production of coastal bermudagrass forage, by nitrogen and limestone rates, 1961–63.

TABLE 30.—*The influence of nitrogen rates with and without limestone on vertical distribution of exchangeable calcium and magnesium in a Cecil sandy loam profile, October 1963*

Soil depth (inches)	Exchangeable Ca and Mg (meq/100 g) at rate of nitrogen applied (lb/acre)				
	0	200	400	800	1,600
	No limestone				
0–6	0.69	0.37	0.25	0.27	0.17
6–12	.34	.36	.27	.24	.21
12–18	.35	.39	.33	.42	.33
18–24	.30	.38	.38	.37	.29
	18 tons limestone per acre				
0–6	3.14	3.51	3.03	2.05	2.05
6–12	1.66	2.19	2.12	2.14	1.56
12–18	.47	.81	1.01	1.32	1.15
18–24	.31	.46	.69	1.12	1.09

The exchangeable Ca+Mg results of table 30 confirm the pH data. Bases were increased markedly to the 12-inch depth by the incorporation of 18 tons of limestone per acre with or without N. As the rate of N was increased, the depth to which limestone affected exchangeable bases increased up to 24 inches at the higher rates of N.

Without limestone, production of coastal-bermudagrass forage declined with years when 400 lb or more of N per acre was added annually (fig. 21). This decrease was associated with a drop in surface-soil pH from 5.3 to below 4.7 (table 29). Where 1,600 lb N/acre was added annually, coastal bermudagrass exhibited severe chlorosis in the fall of 1961, and only a 10 percent stand survived by the fall of 1963, by which time the entire profile pH had dropped to slightly above 4.0. Similarly, at the level of 800 lb/acre, the plants exhibited severe chlorosis by the end of the second year (1962),

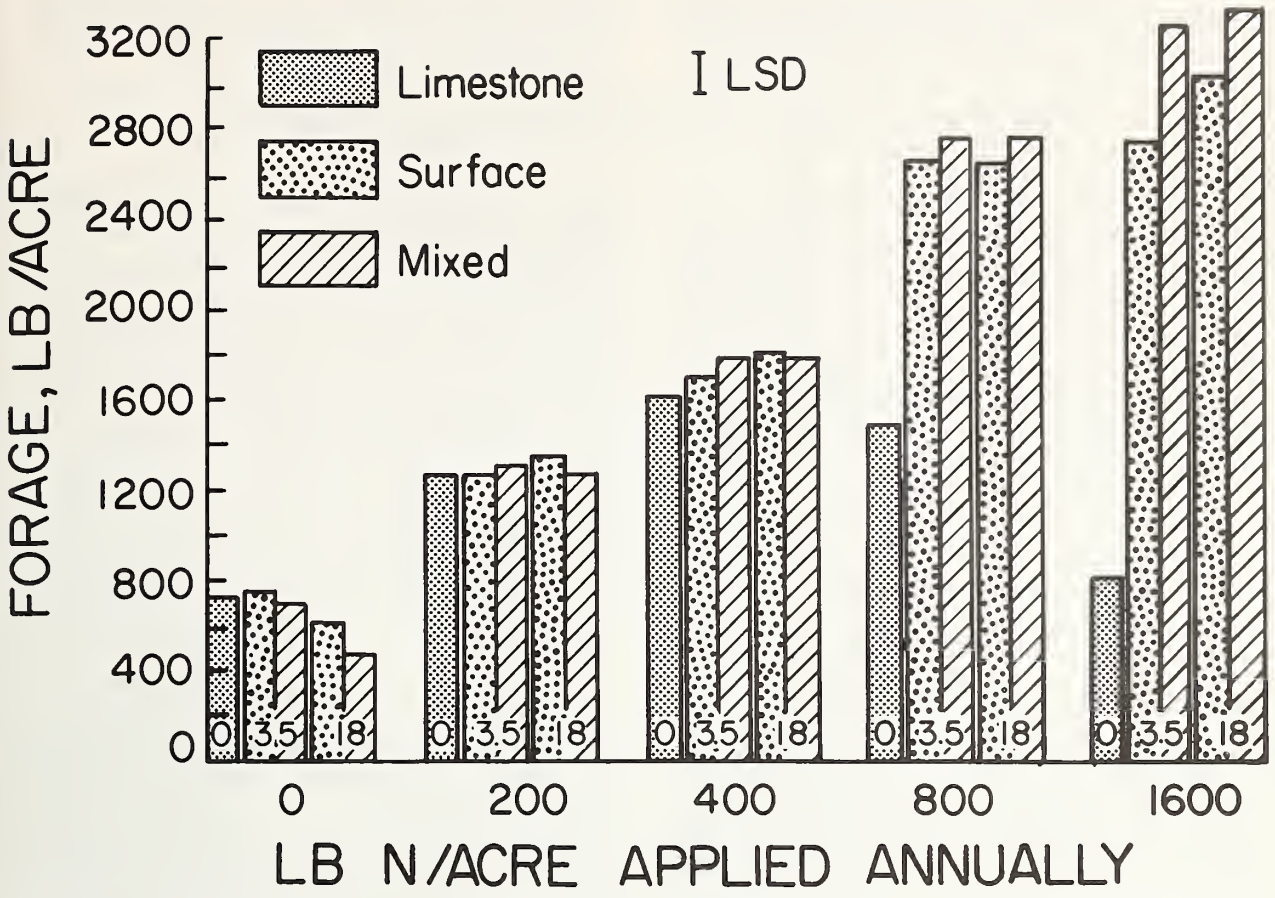

FIGURE 22.—Production of coastal-bermudagrass forage as influenced by limestone rates and placement and nitrogen levels, 3-year average, 1961–63.

and only a 25 percent stand survived 1 year later. In the summer of 1963, the coastal-bermudagrass plants on the treatment of 400 lb N/acre and no limestone were also showing a pronounced chlorosis, and forage production had begun to decline. Thus, within a period of only 3½ years, the pH of this moderately acidic surface soil had been reduced by annual applications of 400 lb N/acre to the point that the yield of coastal bermudagrass was seriously restricted.

The annual trends in forage production were similar for the rates of 3.5 and 18 tons lime per acre; therefore, the data are not shown for the highest rate. At the rate of 3.5 tons of limestone per acre, there was no consistent change with years in production of coastal-bermudagrass forage for the rates of 0, 200, and 400 lb N/acre (fig. 21); but, at the 800- and 1,600-lb levels, forage production declined in the last year of the study when surface pH values had dropped from 5.9 to 4.9 and 4.3, respectively. These results show that an application of 3.5 tons of limestone per acre was barely adequate to offset the residual acidity of annual applications of 400 lb N/acre over a 3½-year period and was inadequate to compensate for 800 lb/acre or higher.

Average annual yields of coastal bermudagrass for the 3½-year period increased with increasing N through the highest rate where soil acidity was not limiting and reached a maximum of 15.0 tons dry matter per acre with 1,600 lb N/acre annually (fig. 22). Forage yields were not increased by limestone at rates of N below 800 lb/acre but were increased sharply at the two highest rates.

Placement of limestone had no appreciable influence on yield except at the rate of 1,600 lb N/acre, where yields on the mixed placement were considerably higher than where the limestone was surface applied (fig. 22).

Coastal bermudagrass growing on the unlimed and high N treatments exhibited severe chlorosis that started as a faint yellowing at the leaf tips and around the margins and gradually progressed inward toward the midrib, suggesting manganese toxicity (*3*).

EFFECT OF TALL FESCUE ON CORN YIELDS

Years of Sod Ahead of Corn

TREATMENTS.—A study of corn after tall fescue and fescue after corn was initiated in 1963 on two comparable areas formerly in 4-year-old tall fescue and in corn, respectively. A new set of plots, with four replicates, was established each year, 1963 to 1968 inclusive, to provide corn 1, 2, . . . , 6 years after grass, and in 1963 to 1967 inclusive, for grass 1, 2, . . . , 5 years after corn. The land was turn-plowed and harrowed to provide a clean seedbed for planting the corn in the spring and the grass in the fall. A recommended corn hybrid was planted to a stand of 15,000 plants per acre in rows 42 inches apart. Fertilization of the corn included 0–50–100 lb N–P_2O_5–K_2O per acre in the row at planting. Half the plots in corn received no N and half received 50 lb N/acre in the row at planting plus 50 lb N/acre as a side dressing about 40 days after planting. Weeds were controlled by cultivation. Fertilization of the fescue included an initial application of 32–50–100 lb N–P_2O_5–K_2O per acre at planting in the fall and an annual application of 32 lb N/acre each spring. All forage and cornstalks were retained on the land. Corn-grain yields were recorded each year to measure the effect of sod on soil productivity. All plots were planted to corn in 1968 to measure the buildup of the soil by the grass, as well as the decline from corn after the grass. Samples of the fescue were taken from each grass plot in March 1968. Aerial portions of the grass were cut 1 inch above ground surface. The stems, dead leaves, and roots were obtained by washing from soil cores 6 inches deep. Soil samples were taken after the land was turned for laboratory determinations of soil nitrogen and carbon content. Soil and plant nitrogen was obtained by the Kjeldahl method and carbon by wet combustion.

Sudax [*Sorghum bicolor* (L.) Moench ×

TABLE 31.—*Corn-grain yields by years after turning tall-fescue sod, with two rates of nitrogen applied to the corn*

Year of record	Nitrogen rate (lb/acre)	Corn-grain yield (bu/acre) after years from sod					
		1st	2d	3d	4th	5th	6th
1963	0	66.7	...	...	...	...	...
	100	95.7	...	...	...	...	...
1964	0	76.1	62.7	...	...	...	...
	100	108.7	106.8	...	...	...	...
1965	0	70.6	77.0	59.9	...	...	...
	100	76.6	76.6	81.5	...	...	...
1966	0	39.2	31.2	28.5	21.8	...	...
	100	44.5	37.5	35.2	35.7	...	...
1967	0	111.9	99.3	78.1	54.3	50.2	...
	100	138.7	134.9	126.8	121.6	122.4	...
1968[1]	0	79.9	88.0	62.4	55.9	45.1	51.1
	100	104.6	108.3	103.4	99.4	96.7	92.1
Average	0	74.1	71.6	57.2	44.0	47.6	51.1
	100	95.6	92.8	85.5	85.6	109.6	92.1
Average increase with nitrogen (%)		29	30	49	95	130	80
1968 increase with nitrogen (%)		31	23	66	76	114	80

[1] Irrigation was used in 1968 to maintain adequate soil water.

Sorghum vulgare var. *sudanense* Hitchc.], a cross between sorghum and sudangrass, was grown in greenhouse pots as an indicator crop on soil from each treatment in 1968. This soil received P and K, but no N, to measure the effect of sod treatments on the capacity of the soil to supply N.

RESEARCH RESULTS.—(*1*) *Corn yields.*—The scheme used in this study for plowing out fescue and planting corn gave corn the first year after sod each year of 1963 through 1968, a second year after sod each year of 1964 through 1968, a third year after sod 1965 through 1968, and so forth, to 6 years continuously after sod in 1968 (table 31). In any year of record, corn yields were highest the first year after sod, both with and without N fertilizer, and generally declined with increasing number of years from sod. Giddens et al. (*12*) reported the relationships of yield to years from sod in 1968 to be

$$Y=108-2.9X, \quad (6)$$

for 100 N to corn, and

$$Y=84-8.0X, \quad (7)$$

for no N to corn, where Y=yield in bushels per acre and X=years from sod. The average corn yield for all years of record was 74 bu/acre with no N to 96 bu/acre with 100 lb N/acre the first year after sod. Similar comparisons were 72 and 93 bu/acre for the two rates of N the second year of corn after sod, and 57 and 86 bu/acre for the third year. The 3, 2, and 1 years of record combined for the fourth, fifth, and sixth year of corn after sod (table 31) gave an average yield of 46.4 and 94.6 bu/acre for 0 and 100 N, respectively. All these yields indicate that the response by corn to 100 lb N fertilizer per acre was 29, 30, 49, and 104 percent for the first, second, third, and fourth or more years after sod. This response suggests that the effect of the grass began to decline in the third year and was gone largely by the fourth year of corn after sod. Conversely, the effect of years in sod showed a buildup in corn yields in 1968 when all sod plots were plowed out and planted in corn (table 32). Corn yields without N increased from 33.0 bu/acre where sod was grown 1 year to 94.6 bu/acre following 5 years of sod, whereas with N, yields were higher but there was only a slight effect of years of sod on yield. Giddens et al. (*12*) showed these responses to be

$$Y=36.3+10.4X, \quad (8)$$

for no N, and

$$Y=94.6+1.42X \quad (9)$$

for 100 N, where Y=yield in bushels per acre and X=years of sod. Where no N was applied, yields of 43.5 bu/acre for corn after corn and 33.0 bu/acre for corn after 1 year of sod (table 32) suggest that there was little N supplied or that there was some tieup of N by this first year of sod. The data on weight and N content of plant residues (table 33) suggest that the N-supplying power of fescue sod is limited the first year but is considerable after 2 or more years. The increase in corn yield from additional years of sod where no N was applied to the corn (table 32), the lack of response to years of sod where N was applied to the corn (table 32), the limited response of corn to N the first couple of years after sod 4+ years old was turned for corn, and the level of N found in the grass residue (table 33) all

TABLE 32.—*Corn-grain yield in 1968 following fescue sod of different ages*

Years of sod	Corn-grain yield (bu/acre) at rate of nitrogen applied to corn (lb/acre)		Increase with nitrogen (percent)
	0	100	
[1]0	43.5	92.8	111
1	33.0	98.5	198
2	64.9	94.5	46
3	80.9	99.8	23
4 }	80.8	100.5	24
5 }			

[1] Corn continuously with 30 lb N/acre annually prior to 1968.

TABLE 33.—*Weight and nitrogen content of fescue tops and roots*[1]

Years of grass after corn	Tops (lb/acre)	Roots (lb/acre)	Nitrogen (%) content of—		Total nitrogen (lb/acre)
			Tops	Roots	
1	650a	1,400a	1.72	0.84	22a
2	5,000b	8,500bc	1.31	.74	129b
3	7,400bc	8,100bc	1.55	.77	177bc
4	8,000c	6,500b	1.34	.87	166b
5	9,800c	10,500c	1.45	.99	250c

[1] Figures in a column followed by the same letter are not significantly different at the 5% level.

indicate that decomposing tall fescue released substantial amounts of nitrogen for use by the corn where the sod was 2 or more years old.

(*2*) *Soil nitrogen and carbon.*—Nitrogen in the soil, determined in the laboratory from samples taken in the field when the soil was turned in the spring of 1968, ranged from about 800 μg/g for the first year of corn following grass to about 600 μg/g in the sixth corn crop after grass. There was no effect from N applied to the corn on this soil-nitrogen level (table 34). Conversely, soil nitrogen ranged from slightly more than 500 μg/g with corn continuously (0 years of grass) to more than 800 μg/g after 5 years of grass. Mathematical expressions for these relationships are

$$Y=800-40Xc, \quad (10)$$

where Y=μg/g N, and Xc=years of corn following fescue, and

$$Y=540+60Xg, \quad (11)$$

where Y=μg/g N, and Xg=years of grass following corn. These formulas show that (1) the N level of the soil is 800 μg/g immediately after sod is turned and declines at the rate of 40 μg/g for each year of corn after sod, and that (2) the N level of the soil for continuous corn is 540 μg/g, and increases at the rate of 60 μg/g for each year of grass after corn. This rate of buildup in N would reach 800 μg/g in 5 years of sod. Giddens et al. (*13*) showed in a greenhouse study with sudax grown in soil from these plots in 1968 that a fairly large portion of the N accumulated in fescue sod is readily available to crop plants.

Carbon levels in the soil (table 34), which are indicative of organic-matter content, followed the same pattern as nitrogen. The percentage of carbon declined with the number of years of corn after grass was plowed out and increased with the number of years the land was in grass. The formulas expressing these relationships were

$$Y=0.84-0.04X, \quad (12)$$

for years of corn after grass, and

$$Y=0.56+0.05X, \quad (13)$$

for years of grass after corn, where Y=percentage of carbon and X=years. Nitrogen applied to the corn had no appreciable effect on the carbon content of the soil.

Relation of Land Slope to Yield of Corn After Sod

TREATMENTS.—Field experiments were conducted in Georgia and South Carolina on land classes B, C, and D with slopes 2 to 6, 6 to 10,

TABLE 34.—*Soil nitrogen and carbon in 1968 where corn followed fescue sod and where fescue followed corn*

Cultural practice		Nitrogen applied to corn (lb/acre)			
Year	Number of years	0	100	0	100
Year fescue was plowed out:	Years of corn following fescue:	Carbon (%)		Nitrogen (μg/g)	
1968	1	0.81	0.82	720	832
1967	2	.44	.73	650	626
1966	3	.79	.78	772	698
1965	4	.57	.80	628	750
1964	5	.74	.62	635	612
1963	6	.53	.75	528	617
Year the fescue was planted:	Years of grass following corn:				
1968	[1]0	.56	...	515	...
1967	1	.60	...	638	...
1966	2	.72	...	671	...
1965	3	.69	...	689	...
1964	4	.77	...	715	...
1963	5	.87	...	876	...

[1] Corn continuously, 1963–68.

TABLE 35.—*Yield of first-year corn following 5 years of tall fescue on three land-slope classes*[1]

Site	Slope class	Corn yield (bu/acre) in—				
		1961	1962	1963	1964	1965
1	B	84a	65a	53a	96ab	75a
	C	86a	59a	46a	88a	75a
	D	80a	50a	52a	102b	84b
2	B	121a	24a	76a	101b	93c
	C	114a	28a	65a	92b	80b
	D	112a	26a	68a	85a	71a
3	B	57a	33a	116b	118c	111b
	C	64a	29a	94a	107b	87a
	D	...	...	106ab	96a	86a
4	B	...	...	66a	106b	96a
	C	...	...	79a	102b	98a
	D	...	...	73a	91a	90a
5	B	93a	24a	...	...	...
	C	92a	25a	138a	123a	79a
	D	95a	29a	125a	121a	84a
6	B	...	...	87a	113a	52a
	C	87a	22a	73a	122b	62b
	D	87a	30a	76a	120ab	65b
7	B	90a	50a	107a	121a	63a
	C	100a	53a	109a	127a	67a
	D	...	...	105a	121a	63a

[1] Yields between slopes at any site in any year are not significantly different at the 5% level when followed by the same letter.

TABLE 36.—*Effect of nitrogen and phosphorus on corn yields following a 5-year sod at six locations in the southern Piedmont in 1961 and 1962*[1]

Site	Year	Corn yields (bu/acre) at rate of nitrogen-phosphorus applied (lb/acre)							
		0–0	0–18	40–0	40–36	80–18	120–0	120–36	160–18
1	1961	74ab	68a	83bc	85bc	87c	87c	92c	88c
	1962	58a	54a	66a	54a	62a	57a	58a	56a
2	1961	113a	117a	111a	115a	116a	117a	117a	119a
	1962	27a	30a	26a	25a	23a	23a	25a	29a
3	1961	56a	43b	63a	62a	64a	67a	64a	64a
	1962	32a	28a	26a	33a	31a	33a	33a	32a
5	1961	72a	72a	92b	89b	102c	105c	104c	109c
	1962	24a	29a	25a	28a	25a	26a	26a	23a
6	1961	66a	64a	76a	87b	94b	92b	108c	109c
	1962	21a	25a	14a	31a	30a	18a	35a	33a
7	1961	77a	72a	91b	84ab	105c	107c	114c	111c
	1962	53a	50a	49a	54a	53a	48a	53a	53a

[1] Yields at a given location for a given year are not significantly different at the 5% level when followed by the same letter.

and 10 to 15 percent, respectively. Corn followed tall-fescue sod that was 5 or more years old in each case. The sod was turned, the land harrowed, and 'Dixie-82' hybrid corn was planted in 42-inch rows to an established stand of 10,000 plants per acre.

Fertilizer variables of different rates of N and P, with a uniform rate of 125 lb K/acre, were superimposed. Corn was cultivated two or more times as needed. Corn in succeeding years was planted on new areas after sod as well as after the previous year or years of corn.

RESEARCH RESULTS.—Yield data in table 35 show that there was no effect of land slope on corn yields for the first year of corn after the grass during any of the 5 years of record on most sites. The yield decrease with slope increase on site 4 in 1964 is inconsistent with the increase in yield with increase in slope on site 6 that year.

The wide difference in yield from year to year was due to rainfall distribution. Rainfall amounts during the corn-growing period were least in 1962 and greatest in 1964 (*15*). Analyses of rainfall records in relation to corn yields showed that weekly rainfall amounts during the 9th, 10th, 11th, and 12th weeks after plant emergence were closely correlated with yield. When the rainfalls received during the 10th, 11th, and 12th weeks were combined, the correlation coefficient with corn yields was 0.92.

Parks et al. (*15*) reported that yields of corn declined with succeeding years of corn following sod. This is consistent with the findings of Giddens et al. (*13*).

Yields were affected more by rainfall amounts in 1961 versus 1962 than by fertilizer amounts in either year (table 36). There was no response to fertilizer in 1962 because of limited rainfall at all sites, and at site 3 in 1961. There was no significant increase in yield above an N rate of 0 lb/acre at sites 2 and 3, 40 lb/acre at site 1, 80 lb/acre at sites 5 and 7, and 120 lb/acre at site 6. Poultry litter applied for 4 years previously at site 2 caused the lack of response to fertilizer there. A slight response to P was noted at site 6 where the available P and pH were low in the soil.

CORN AFTER SERICEA LESPEDEZA

TREATMENTS.—Corn was planted after 10-year-old sericea lespedeza (*Lespedeza cuneata* Don.) in 1964, and then continued on the same area for 5 successive years through 1968 to determine the nutrient requirements of corn on such land. Combinations of $N–P_2O_5–K_2O$ fertilizer included rates of 0, 30, 60, 90, and 120 lb/acre of each fertilizer element to give 0 to 120 lb N/acre with 60 lb P_2O_5/acre, and 120 lb K_2O/acre; 0 to 120 lb P_2O_5/acre with 120 lb N/acre and 120 lb K_2O/acre; and 0 to 120 lb K_2O/acre with 120 lb N/acre and 60 lb K/acre. A 0–0–0 treatment was also included. A split-plot design with four replications was used. A method-of-planting study included (1) conventional tillage, with land turnplowed, harrowed one or more times for a seedbed, planting with conventional planter, and cultivation for weed control, versus (2) planting with lister planter without prior tillage, and cultivation for weed control. Fertilizer variables in this method-of-planting study included 0–0–0 and 120–120–120 lb $N–P_2O_5–K_2O$ per acre, respectively, with four replicates of each tillage × fertilizer treatment. Sericea stalks were chopped with a rotary cutter prior to initial tillage in 1964, and cornstalks were cut in similar manner each year thereafter. All P and K fertilizer was banded under the row at planting, with 20 lb N/acre for those treatments receiving N. The remainder of the N was applied beside the row at the second cultivation about 40 days after planting. Rows were 42 inches apart. The soil was Cecil sandy loam on 2- to 4-percent slope.

RESEARCH RESULTS.—The 10-year accumulation of sericea leaves and stems above ground weighed 12 tons per acre prior to land preparation when the sericea land was planted to corn. Nitrogen in these residues and the soil to plow depth mineralized quickly, as the ammonium-N declined and nitrate-N increased during a 203-day incubation period (table 37). More extractable N occurred in the soil and leaves than in the stems.

Corn yields varied widely from year to year as a result of differences in rainfall, being highest and about equal the first and fourth years, and extremely low the third year (table 38). There was no response from any fertilizer treatment the third year when water was the limiting factor, and those yields are not considered in the remaining discussions except where the 5-year average is used. There was a

TABLE 37.—*Ammonium and nitrate nitrogen in leaves, stems, and soil (0–6 inches) where sericea lespedeza was grown 10 years*

[Micrograms per gram]

Source	Incubation period (days)							
	7		28		134		203	
	NH_4	NO_3	NH_4	NO_3	NH_4	NO_3	NH_4	NO_3
Soil	12.5	10.5	11.9	22.4	5.7	74.8	5.0	119.2
Leaves	13.6	30.3	24.9	51.5	6.7	173.2	6.0	225.9
Stems	13.9	3.9	18.0	6.5	7.4	33.2	5.3	73.4

TABLE 38.—*Yield of corn following 10 years of sericea lespedeza with different rates of nitrogen, phosphorus, and potassium applied to the corn*

[Bushels per acre]

$N–P_2O_5–K_2O$ applied to corn (lb/acre)	Years after turning lespedeza					Average
	1	2	3	4	5	
0–0–0	88.6	59.0	8.6	64.8	27.2	49.6
0–60–120	83.6	52.7	8.4	72.4	22.9	48.0
30–60–120	94.1	55.4	12.4	91.8	43.0	59.3
60–60–120	103.5	56.5	6.8	104.9	56.3	65.6
90–60–120	111.0	55.5	7.0	112.5	58.0	68.8
120–60–120	108.7	58.9	9.8	124.7	66.3	73.7
120–0–120	93.7	61.3	5.3	119.5	51.1	66.2
120–30–120	102.9	56.2	3.8	118.7	53.5	67.0
120–90–120	105.0	53.2	6.9	120.6	68.9	70.9
120–120–120	107.4	55.8	4.3	119.1	66.0	70.5
120–60–0	96.7	56.3	8.3	105.0	55.7	64.4
120–60–30	99.0	57.6	3.6	111.1	55.6	65.4
120–60–60	104.1	57.4	4.4	111.3	61.3	67.7
120–60–90	106.6	56.9	4.3	113.6	63.8	69.0

negative response to P–K without N (0–0–0 versus 0–60–120) the first, second, and fifth years, but a positive response the fourth year, averaging to little effect from P–K where no N was added to the soil. There was a positive response to N all years (fig. 23) when P and K were included. Additional P to 60 lb P_2O_5/acre and additional K to all rates applied increased yields all years (fig. 23). The greater yield response from increasing rates of N and K in the fourth year than in the first indicates an increasing need for these elements with successive corn crops.

Corn planted on a plowed and disked seedbed yielded 85.8 and 64.0 bu/acre with and without fertilizer. That planted with the lister planter gave corresponding yields of 84.5 and 55.6 bu/acre (table 39). Corn seed were placed near

TABLE 39.—*Yield of corn following sericea lespedeza with two methods of planting and two levels of nitrogen, phosphorus, and potassium*

Years after turning lespedeza	Corn yield (bu/acre) at rate of $N–P_2O_5–K_2O$ (lb/acre) applied			
	0–0–0		120–120–120	
	Conventional planting	Lister planter	Conventional planting	Lister planter
1	100.4	73.4	114.1	100.5
2	77.6	65.6	76.1	82.6
3	14.1	15.0	18.3	15.5
4	85.1	74.1	143.4	152.0
5	42.8	50.0	74.9	71.8
Average	64.0	55.6	85.8	84.5

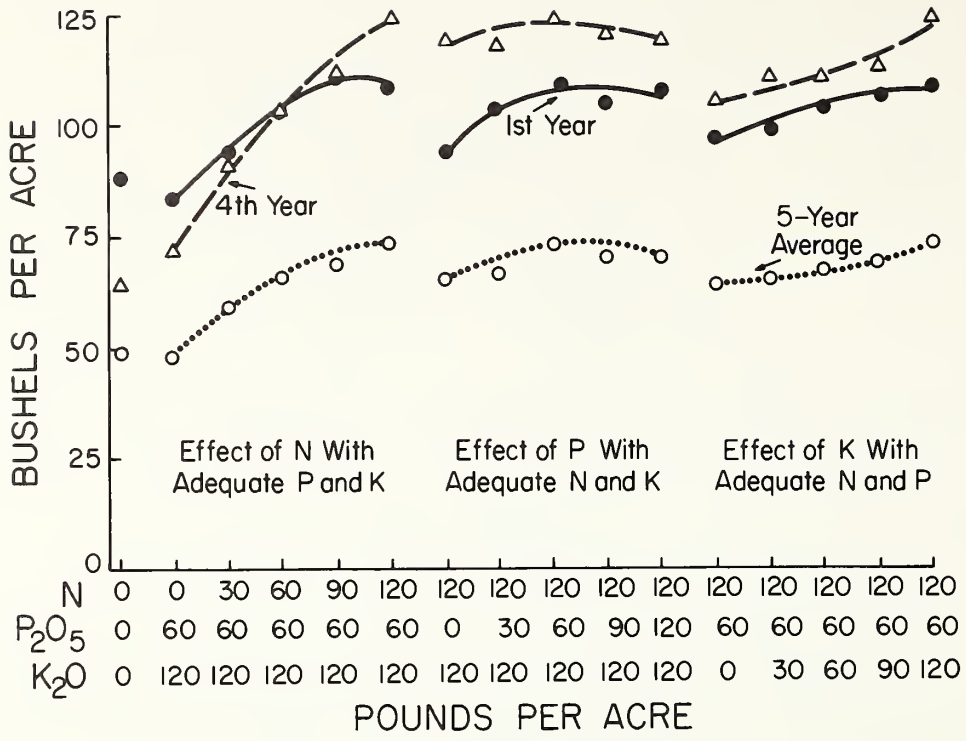
BUSHELS PER ACRE
125
100
75
50
25
0
4th Year
1st Year
5-Year Average
Effect of N With Adequate P and K
Effect of P With Adequate N and K
Effect of K With Adequate N and P
N 0 0 30 60 90 120 120 120 120 120 120 120 120 120 120 120
P2O5 0 60 60 60 60 60 0 30 60 90 120 60 60 60 60 60
K2O 0 120 120 120 120 120 120 120 120 120 120 0 30 60 90 120
POUNDS PER ACRE

FIGURE 23.—Corn yields after sericea lespedeza with various rates of nitrogen, phosphorus, and potassium applied to the corn.

the subsoil in the lister furrow. These young plants grew slowly and suffered nutritional deficiencies that were never overcome by the unfertilized plants.

Results from this study show that (1) crops following sericea that had received little or no fertilizer for several years will respond to N–P–K, (2) sericea residue will not overcome drought effects from inadequate rainfall, and (3) tillage method is relatively unimportant when nutritive requirements are met and weeds are controlled (*2*).

INTERSEEDING OTHER CROPS IN COASTAL BERMUDAGRASS

Tall Fescue and Coastal Bermudagrass

TREATMENTS.—Tall fescue was seeded into dormant coastal bermudagrass October 18, 1963, in rows 10 inches apart, using a John Deere grassland drill on Cecil sandy loam, class II land. Half of the area was sprinkler-irrigated and the other half received rainfall only. Main plots were clipping heights at 2 and 4 inches with five replications. Subplots were five nitrogen levels to the coastal bermudagrass with rates of 25, 50, 75, 100, and 150 lb N/acre applied after each clipping. Phosphorus and potassium were added uniformly to all plots, as was nitrogen to the fescue in the fall and early spring.

Fertilizer was applied (lb/acre) uniformly to the fescue as follows:

Date	N	P_2O_5	K_2O
Oct. 18, 1963	50	50	50
Feb. 6, 1964	75	...	...
Oct. 6, 1964	50	50	50
Feb. 5, 1965	75	...	...
Nov. 10, 1965	50	50	50
Mar. 2, 1966	75	...	...

Nitrogen was applied to the coastal bermudagrass at the prescribed split-plot rates on April 15, June 11, July 14, and August 13, 1964; April 28, June 2, July 2, August 3, and September 8, 1965; and May 6, June 14, July 8, August 18, and September 29, 1966. Phosphorus and potash were applied to all plots: 150 lb P_2O_5 and K_2O each per acre on April 15 and on July 14, 1964, and in like amounts on April 28 and July 2, 1965. In 1966, the phosphorus and potash were applied each time nitrogen was

TABLE 40.—*Annual yield of forage with an association of tall fescue and coastal bermudagrass*

Year	Grass association	Annual fertilizer application, $N-P_2O_5-K_2O$ (lb/acre)	Forage yield (tons/acre) for—			
			Unirrigated		Irrigated	
			2-in clipping height	4-in clipping height	2-in clipping height	4-in clipping height
1964	Fescue and coastal	225–350–350	4.7	3.6	4.8	4.7
	.... do	325–350–350	5.9	5.0	6.2	5.5
	.... do	425–350–350	7.0	5.7	7.9	6.2
	.... do	525–350–350	7.4	6.4	8.4	7.5
	.... do	725–350–350	7.9	7.0	8.5	8.0
	Coastal only	425–350–350	6.9	6.4	6.8	6.4
1965	Fescue and coastal	250–350–350	4.8	3.6	4.9	4.5
	.... do	375–350–350	6.3	5.7	7.7	7.1
	.... do	500–350–350	8.7	7.0	10.2	8.1
	.... do	625–350–350	8.4	7.0	10.3	9.8
	.... do	875–350–350	8.9	7.3	10.3	10.0
	Coastal only	500–350–350	8.2	7.2	9.6	8.4
1966	Fescue and coastal	250–147–125	3.8	3.4	4.5	3.0
	.... do	375–192–200	5.5	4.9	6.2	4.8
	.... do	500–265–275	5.9	5.5	7.6	5.8
	.... do	625–335–350	6.5	5.9	7.7	7.1
	.... do	875–477–500	6.9	5.7	7.5	7.1
	Coastal only	500–265–275	5.7	5.9	7.2	6.1

applied at P_2O_5 and K_2O rates equal to one-fourth and one-half, respectively, the rates of N. The total amounts of N, P_2O_5, and K_2O applied each year are shown in table 40.

All plots received 4 tons of lime per acre on May 6, 1966. Water was added to the irrigated plots as follows: 1964: May 21, 1.5 in; May 26, 1.5 in; June 12, 2.0 in; June 22, 3.0 in; total, 8.0 in; 1965: May 11, 2.0 in; May 20, 2.0 in; June 3, 2.0 in; July 23, 2.0 in; July 7, 0.6 in; and Nov. 10, 1.25 in; total, 9.85 in; 1966: July 8, 11, 22, 25, and 29, 1.25 in each date; and Sept. 6, 2.0 in; total, 8.25 in.

The coastal bermudagrass was clipped for forage yields immediately ahead of the fertilizer applications in May, June, July, August, and September each year.

RESEARCH RESULTS.—The initial stand of tall fescue was excellent on all plots. Yield data (table 40) show that yields of the combinations of coastal bermudagrass and fescue varied from 3 tons per acre at the low N rate, 4-inch clipping height in 1966 to 10.3 tons per acre at the high N rate, 2-inch clipping height with irrigation in 1965. Irrigation increased yields slightly each year on all but the two lowest N rates at the 4-inch clipping height in 1966. Yields were higher with the 2-inch than with the 4-inch clipping height on all fertility levels and irrigation treatments (fig. 24). Yields were increased with nitrogen to about 700 lb N/acre (fig. 24) under both clipping and irrigation treatments.

Yields of coastal bermudagrass without fescue were higher with the 2-inch clipping than the 4-inch clipping and with the irrigation on both heights of cut (table 40). The 3-year average yields for the 2- and 4-inch cuts were 6.9 and 6.5 tons per acre without irrigation and 7.9 and 6.6 tons per acre with irrigation. Comparable yields for the coastal bermudagrass plus fescue were 7.2 and 6.1 tons per acre without irrigation and 8.6 and 6.7 tons per acre with irrigation.

Fescue content of the harvested dry matter decreased from a high in early spring to practically zero in midsummer, except at the lowest N levels under irrigation at the 4-inch clipping height, and then rose again in the fall (fig. 25). Fescue grew throughout the summer period at the rate of 250 lb N/acre, 4-inch clipping height, under irrigation. The amount of fescue was negatively related to the favorableness of the growth period for coastal bermudagrass.

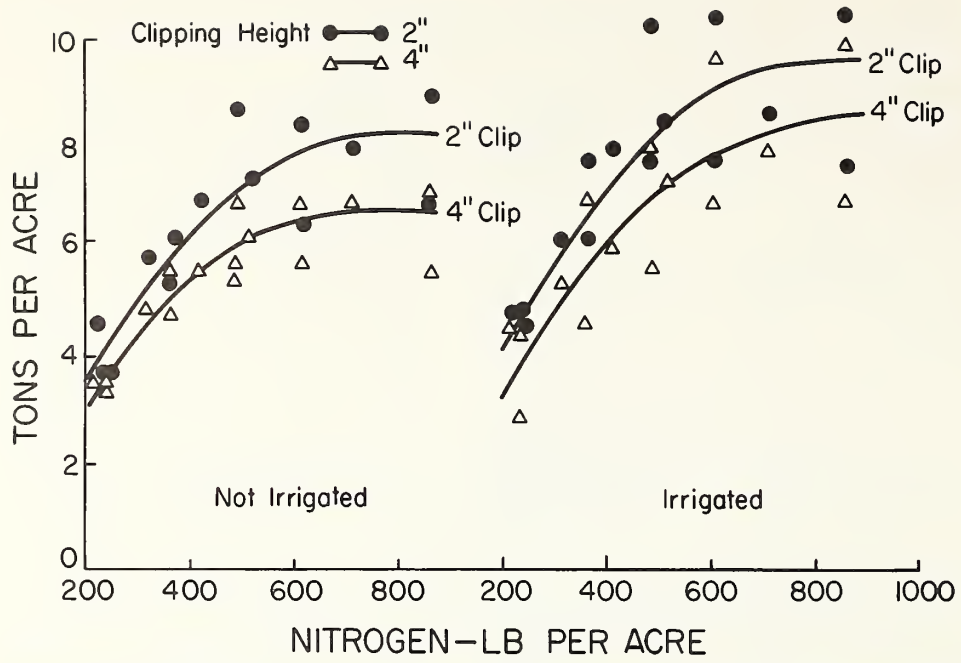

FIGURE 24.—Yield of coastal bermudagrass and tall fescue with four rates of nitrogen, irrigated versus unirrigated, and clipped at heights of 2 and 4 inches.

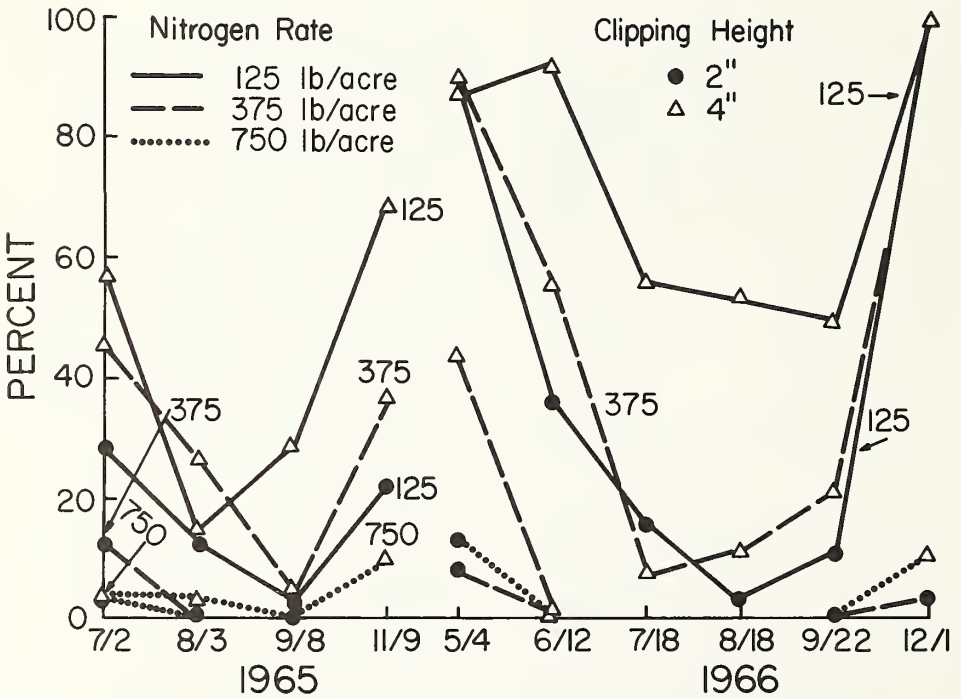

FIGURE 25.—Percentage of fescue in forage harvested at different dates.

Nitrogen fertilization decreased fescue content, whereas clipping at the 4-inch height increased fescue content. Irrigation increased fescue content, particularly at the lower fertility levels and 4-inch clipping height.

Invasion of tall fescue into the originally coastal-only treatments was favored by the 4-inch clipping height at the irrigated location. This finding illustrates the ease of establishing tall fescue in dormant coastal-bermudagrass sod when soil moisture and fertility are adequate.

Wilkinson et al. (*20*) reported that reduced yields in 1966, as compared with those in 1965, under irrigated conditions suggested the possibility of K deficiency, although yields in 1964 (four harvests) were similar to those in 1966 (six harvests). Coastal bermudagrass and fescue samples from all replicates of the 2- and 4-inch clipping heights of the treatments of 250, 375, and 875 lb N/acre from the irrigated location were analyzed for K for each of the six harvests made in 1966. Clipping height affected K content little; consequently, clipping-height results were averaged (table 41). Harvest-date effects on K content were highly significant ($P<0.01$) and related to time of K fertilization. These results suggest adequate K at all N rates at all harvests, except for potentially marginal concentrations of K in coastal bermudagrass at the July 18 and September 22 clippings for the treatments of 375 and 875 lb N/acre. These nitrogen levels significantly reduced K content of coastal bermudagrass ($P<0.01$). Previous research has shown almost certain K response below 1.1 percent K in the top growth, but little or no response above 1.4 to 1.5 percent in coastal bermudagrass (*4*).

Tall fescue contained more K than coastal bermudagrass at the lower N levels from the June 13 harvest to the end of the season (table 41). Assuming 1.5 percent K as an adequate K content, K appears not limiting to tall fescue at N rates up to 375 lb N/acre. The statistical significance of N fertilization on K content was not tested because of incomplete replications. Soil-test results at the end of the experiment indicated a medium to high P level, but a low level of available K, even though 1,200 lb K_2O/acre was applied over a 3-year period. A calculation of K removed in the crop shows 1,945 pounds K removed in 65 tons of forage, assuming 1.5 percent K for the forage during the 3-year period. Luxury consumption of K following application in the two previous harvest years and a trend toward higher K in fescue could account for the difference in K. Both grasses remove large amounts of K from the soil, particularly where N is not limiting yield.

Although K deficiency perhaps contributed to decreased fescue content at the highest level of N fertilization, probably the primary mechanism for the effect of clipping height and N fertilization involved competition for light. Increasing levels of N fertilization increased growth rate and height of coastal bermudagrass, thereby shading fescue because of its smaller growth rate response to N. The tall fescue also was somewhat elongated as a consequence of the shading by the coastal bermudagrass. Under this condition most of the green leaves of tall fescue were removed when clipped at 2 inches. As the summer progressed and temperature and plant water stresses increased, recovery of tall fescue may have been affected by depletion of reserve carbohydrates, as well as by the removal of leaf area. These observations suggest that this association must be managed by N fertilization to keep growth rates more comparable, and yet clipping must be frequent enough to prevent dominance of coastal bermudagrass over tall fescue.

The object of an association of coastal bermudagrass and tall fescue should not be an even

TABLE 41.—*Potassium in coastal bermudagrass and tall fescue as affected by harvest date and nitrogen fertilization at the irrigated location during 1966*

Total nitrogen (lb/acre/yr)	Potassium (%) at various harvest dates					
	May 4[1]	June 13	July 18[1]	Aug. 18	Sept. 22[1]	Dec. 1
	Coastal bermudagrass					
250	2.5	2.2	1.4	1.9	1.6	([2])
375	2.3	1.7	1.3	1.4	1.6	1.1
875	1.7	1.5	1.1	1.8	1.2	1.4
	Tall fescue					
250	2.0	2.9	2.7	2.7	2.3	1.9
375	1.5	2.3	2.4	2.5	1.9	2.4
875	.7	2.1	2.2	([2])	2.0	([2])

[1] Potassium fertilizer applied after forage was removed.

[2] Insufficient forage sample for analysis.

balance between species at all times of the year. Failure to raise greatly total dry-matter production over coastal bermudagrass grown alone, even though a growing crop is on the land over a longer period, raises the question: What has been gained? One advantage may be more even distribution of dry matter during the year, which is of value for cow-calf beef cattle enterprises, particularly where the animal does the harvesting. Competition from fescue may reduce summer growth of coastal bermudagrass at low N levels, but this may not be critical since coastal-bermudagrass pastures in summer in the southern Piedmont outproduce the stocking rates they maintain in spring and fall. An aim for this association should be for tall fescue to contribute to yield in early spring and fall when coastal bermudagrass grows slowly, or not at all, and be dormant and not compete with coastal bermudagrass during summer.

Crop-management systems that encourage cool-season perennials to persist and grow on the same land area as warm-season perennials with a minimum of direct competition have great potential in the southern Piedmont. Such systems protect the quality of our soil and water resources, as well as utilize climate, soil, and water resources. Associations of tall fescue and coastal bermudagrass appear well suited to cow-calf operations in the southern Piedmont. An association of tall fescue and coastal bermudagrass has been grazed successfully in grazing studies at the Southern Piedmont Conservation Research Center since 1965. Calf weight gains averaged over 4 years have been 386 lb per acre (S. R. Wilkinson and J. A. Stuedemann, 1976, personal communication).

Wheat and Coastal Bermudagrass

Experiment 1

TREATMENT.—Wheat, *Triticum aestivum* L., cultivar 'Georgia 1123', was seeded for 4 years at 1½ bu/acre with a John Deere grassland drill into dormant coastal bermudagrass, fertilized with 0, 40, 80, 120, and 160 lb N/acre per year, and harvested either as forage (silage stage of maturity) or grain. To compare coastal-bermudagrass yield without sod-seeded wheat, an additional treatment of coastal bermudagrass only (CO) was included. Experimental plot size was seven rows 10 inches apart, 20 feet long, with the middle three rows, 15 feet long, harvested for yield. The experiment was arranged in a split-plot, randomized, complete block design with six replications. Methods of harvest were main plots, and nitrogen rates were split plots. Phosphorus and po-

TABLE 42.—*Cultural operations and dates conducted for experiment 1*

Cultural operation	1966	1967	1968	1969
Planting[1]	11–01–65	10–19–66	11–03–67	11–01–68
Fertilization for wheat[2]	3–02–65	3–08–67	3–20–68	3–12–69
Silage harvests	5–03–66	5–15–67	5–20–68	5–13–69
Grain harvests	6–17–66	6–15–67	6–21–68	6–13–69
Fertilization for coastal[3]	5–03–66*	5–17–67*	5–21–68*	5–14–69*
Do[3]	6–20–66*	6–16–67	6–24–68	6–13–69
Do[3]	7–28–66	7–28–67*	7–31–68*	7–18–69*
Do[3]	9–02–66	9–06–67	9–09–68	8–22–69
Coastal harvests	6–17–66	6–15–67	6–21–68	6–13–69
Do	7–28–66	7–24–67	7–31–68	7–17–69
Do	9–02–66	9–06–67	7–09–68	8–21–69
Do	10–13–66	11–08–67	11–01–68	10–02–69

[1] 'Georgia 1123' wheat was seeded in rows 10 inches apart at a seeding rate of 1½ to 2 bu/acre. Seeding was accomplished with a John Deere grassland drill.

[2] One-third of N was applied at planting time with two-thirds applied at time indicated. Approximately 100 lb P_2O_5 and K_2O per acre was applied to the wheat at time of planting.

[3] One-fourth of annual rate of N for coastal bermudagrass was applied on each date. P_2O_5 and K_2O were applied on dates indicated with an asterisk to give a 4:1:2 $N:P_2O_5:K_2O$ ratio on an annual basis. An additional 200 lb P_2O_5 and K_2O per acre was applied to all plots on November 23, 1966, because soil-test levels indicated low levels of phosphorus and potassium.

tassium were applied in a 4:1:2 ratio of $N:P_2O_5:K_2O$ to insure that they were not growth-limiting. Cultural data for wheat and coastal bermudagrass are indicated in table 42. The last harvest of coastal bermudagrass was timed to remove most of the accumulated top growth before sod-seeding.

RESEARCH RESULTS.—(*1*) *Wheat yields.*—The top grain yield (31.6 bu/acre) was obtained in 1966, with 160 lb N/acre applied (table 43). Grain yields were lower in 1967 and 1968 because of poorer initial stand of wheat. In 1969, grain yields were reduced because of excessive bird damage and, consequently, grain yields are not shown (table 43). In general, straw yields paralleled grain yields, except in 1969 (table 44). The excessive bird damage suffered in 1969 is illustrated by straw yields similar to those obtained in 1966.

(*2*) *Silage yields.*—After 1966, silage yields increased partly because of an increased contribution of grasses, such as little barley, *Hordeum pusillum* L., and annual ryegrass, *Lolium multiflorum* L. During the last 3 years of the study, these grass weeds extensively infested areas harvested for grain or silage. However, they contributed to the yield of silage or forage for processing. Silage yields included 40 to 60 percent wheat. In successive years, the weed problem in the areas harvested for silage diminished because removal of weed seeds in the silage prevented natural reseeding.

Under the grain-harvest management system, successive sod-seeding resulted in a progressive increase in weeds. This is partially a result of the combination of annual ryegrass, vigorous response to N, its prolific seeding habit, and the late harvest date for wheat. Total silage yield varied less than grain yield during the last 3 years of the study. Dry-matter content of the silage decreased from an average of 38 percent on plots receiving zero N to 33 percent on plots with 160 lb N/acre per year applied to the wheat.

Whether wheat was harvested for silage or grain, to obtain yields worth harvesting, at least 80 lb N/acre per year must be applied. Wilkinson and Langdale (*19*) summarized several studies that suggested that the small grains interseeded into bermudagrass sods will require additional N fertilization to obtain good cool-season grass growth, if the bermudagrass received less than 400 lb N/acre per year. Results of this experiment confirm this N requirement.

(3) *Coastal-bermudagrass yields.*—The yields of coastal bermudagrass, as affected by method of wheat harvest (silage or grain) and nitrogen level to wheat, are given in table 45. The lower coastal-bermudagrass yields indicated in the silage harvesting system are primarily due to some coastal bermudagrass being harvested in wheat-silage yields and a relatively short first summer growth period (May to June). Comparisons for the effect of wheat on

TABLE 43.—*Yield of* 'Georgia 1123' *wheat harvested as grain or silage when sod-seeded in dormant coastal-bermudagrass sod*

Nitrogen applied to wheat (lb/acre)	Wheat yield				
	Year of harvest				Average
	1966	1967	1968	1969[1]	
	Grain (bu/acre)				
0	5.0	3.0	2.9	...	3.6
40	11.6	7.0	10.8	...	9.8
80	17.0	14.2	16.0	...	15.4
120	28.7	19.0	15.9	...	21.2
160	31.6	19.5	24.6	...	25.2
	Silage (tons dry matter per acre)				
0	0.6	1.0	1.3	0.7	0.9
40	1.0	1.8	2.6	1.7	1.8
80	1.6	2.6	3.4	2.5	2.5
120	1.6	2.9	3.4	2.9	2.7
160	2.5	3.1	3.6	2.9	3.0
CO[2]	...	.7	.9	.5	.7

[1] Grain yields in 1969 are not shown because of previous harvesting by birds and excessive grassy-weed competition. Consequently, they were not included in averages.

[2] CO = undisturbed coastal-only plots associated with each harvest system. They did not receive N in the fall. Yields are for the winter and spring periods only.

TABLE 44.—*Wheat-straw yield as affected by nitrogen fertilization and year*

[Tons dry matter per acre]

Nitrogen applied to wheat (lb/acre)	Wheat-straw yield				
	Year of harvest				Average
	1966	1967	1968	1969	
0	0.5	0.1	0.2	0.2	0.3
40	.9	.2	.7	1.2	.8
80	1.2	.5	1.1	1.8	1.2
120	1.6	.7	1.2	1.5	1.3
160	1.7	.8	1.2	1.5	1.3

accumulative annual coastal-bermudagrass yields should be based on the same harvest system. Coastal-bermudagrass reductions for sod-seeded wheat harvested for grain receiving 160 lb N/acre as compared with yields for coastal-only plots were 1.0, 0.7, 1.8, and 0.8 tons per acre for the first, second, third, and fourth years, respectively. Average hay-yield reduction resulting from the overseeded wheat was 1.1 tons per acre. Under the silage-harvest system at the level of 160 lb N/acre to wheat, average yield reduction was only 0.4 ton. Increased levels of N fertilization increased the density of the wheat crop and reduced early spring growth of coastal bermudagrass. Carryover of available N to coastal bermudagrass was not indicated.

(*4*) *Soil-test levels.*—Potassium declined when 120 and 160 lb N/acre per year were applied to wheat harvested either as silage or grain. Potassium reserves were depleted in spite of substantial levels of K_2O input (1,040 lb K_2O over a 4-year period). Phosphorus soil levels increased over the experiment, suggesting that perhaps more phosphorus was applied than needed.

Gross income comparisons are listed in table 46 for the three crop systems as affected by the three highest N applications to wheat. Gross returns were highest from 120 lb N/acre to sod-seeded wheat harvest for grain and lowest from the coastal-bermudagrass-hay systems.

TABLE 45.—*Coastal-bermudagrass yield as affected by nitrogen applied to wheat and method of harvesting wheat*

[Tons of dry matter per acre]

Nitrogen applied to wheat (lb/acre)	Year of harvest[1]									
	1966		1967		1968		1969		Average	
	S	G	S	G	S	G	S	G	S	G
0	5.0	4.9	7.6	9.1	6.8	8.1	6.5	7.0	6.5	7.3
40	5.4	4.8	7.7	9.2	6.8	7.9	6.7	7.3	6.7	7.3
80	5.4	5.3	7.6	9.4	6.5	7.5	6.5	6.9	6.5	7.3
120	5.4	4.6	7.7	8.7	6.5	7.7	6.7	7.0	6.6	7.0
160	5.4	4.7	7.6	8.6	6.3	6.6	6.8	6.6	6.5	6.6
CO[2]	5.7	5.7	7.9	9.3	6.8	8.4	7.0	7.4	6.9	7.7

[1] S refers to wheat harvested as silage; G refers to wheat harvested as grain.

[2] CO are undisturbed coastal-only plots associated with each harvest system. They did not receive N in the fall. Yields are for the summer period.

However, since these are gross returns, the producer must decide if the additional increase in gross income will pay for the costs of seeding, fertilization, and harvesting. The general yield levels were low in the last 2 years of experiment 1. However, with good management practices, including good varieties, yields of 30 bu wheat/acre can readily be obtained. This, plus probable higher wheat prices, indicates that the practice would be economically profitable. The presence of wheat stubble and straw would reduce the general quality of the first harvest of coastal bermudagrass. Overall, the silage or processed forage harvest method appears practical for most situations. However, increased grain prices could modify this picture considerably.

Experiment 2

TREATMENTS.—'Blueboy' wheat was seeded in rows 22 inches apart at a rate of 1½ bu/acre on October 30, 1968, October 15, 1969, and October 23, 1970 with an experimental sod-seeder (USDA F–74) modified to give two seeding methods: (1) rotary cultivation of a 4-inch sod strip followed by double-disk openers and a rear press wheel with a seed-firming rib, and (2) notched colters (replacing the rotary cultivation) followed by a spear-point opener used similar to a John Deere grassland

TABLE 46.—*Gross income[1] from coastal bermudagrass only, coastal plus sod-seeded wheat for grain, or silage as affected by nitrogen applied to wheat*

[Dollars per acre]

Cropping-system returns	Nitrogen applied to wheat (lb/acre)		
	80	120	160
Grain	61.60	84.80	100.80
Straw	18.00	19.50	19.50
Coastal hay	292.00	280.00	264.00
Total	371.60	384.30	384.30
Silage (forage)	100.00	108.00	120.00
Coastal hay	260.00	264.00	260.00
Total	360.00	372.00	380.00
Coastal hay[2]	308.00	308.00	308.00

[1] Grain @ $4/bu, silage and coastal hay @ $40/ton, straw @ $15/ton. Yield levels were obtained from tables 43, 44, and 45 for grain, straw, and coastal hay, respectively.

[2] Nitrogen was applied to coastal-only plots during summer growth period.

drill. The net effect of the planting methods was to plant in a 4-inch rototilled area of bermudagrass or to plant in a slit in the grass made by the notched colter and spear-point opener. The same areas were planted for 3 years (1968–70), 2 years (1969–70), and 1 year (1970). Individual plot size was four rows spaced 22 inches apart with the middle two rows, 15 ft long, harvested for yield.

All plots were fertilized with 1,000 lb 5–10–15/acre before planting, and an additional 60 lb N/acre per year was applied in February. Grain was harvested June 13, 1969, June 4, 1970, and June 10, 1971, respectively. The effects of planting method and successive years of sod-seeding on early spring growth of coastal bermudagrass and weed yields were evaluated. Subsequent yield and spring and summer growth of coastal bermudagrass were not determined, and the bermudagrass was not fertilized.

RESEARCH RESULTS.—This study was implemented to evaluate further the effect of successively planting the same coastal-bermudagrass sod area and to evaluate two methods of sod-seeding. Yields were quite variable from year to year (table 47), and except for 1969 they were generally higher than those in experiment 1. Yields tended to be better in the first year of planting as compared to the third year of planting the same sod. (See 1971 yields in table 47.) Differences were rather substantial (yields were 10 bu/acre higher on the first planting versus the third year of planting the same sod). However, actual yields increased with each year of planting the same sod, that is, 11.6, 16.2, and 20.4 bu/acre for first, second, and third year, respectively. Bird damage reduced yields in 1969.

In 1971, when yields were the highest, rototilling a 4-inch strip before planting increased average yields about 5 bu over a 3-year period. In view of the additional power and time required, however, rototilling probably would not be economically feasible. The effect of rototilling on subsequent growth of the coastal bermudagrass was not evaluated, but it would likely have some detrimental effect on first-cutting yields. However, the method may have an advantage in reducing competition from the sod in early small grain plantings. Some of the effects observed are likely to be related to a reduced competition for N, since annual N

TABLE 47.—*Effect of planting method and successively planting the same area on grain yields of* 'Blueboy' *wheat*

Planting method	Years planted[1]	Grain yield (bu/acre) in— 1969	1970	1971
Rototill + double disk[2]	3	11.6	16.0	22.2
Colter & shovel openers[3]	3	11.6	16.4	18.6
Rototill + double disk[2]	2	...	31.3	29.5
Colter & shovel openers[3]	2	...	24.3	22.5
Rototill + double disk[2]	1	...	...	39.2
Colter & shovel openers[3]	1	...	...	32.8

[1] 3 = plots planted successively in 1968, 1969, and 1970; 2 = plants planted successively in 1969 and 1970; 1 = plots planted only in 1970.

[2] Rotary cultivation of a 4-inch strip of dormant coastal bermudagrass followed by double-disk opener and rear press wheel with seed-firming rib.

[3] Rolling colter and regular shovel openers similar to that used with John Deere grassland drill. The seeds are planted in a narrow silt.

inputs were 110 lb N/acre, and the results from experiment 1 suggest some response to N up to 160 lb N/acre per year applied to wheat. Weed infestation was not as severe in this experiment as in experiment 1. This difference was attributed to a lower initial weed population in the experimental area.

Oats and Coastal Bermudagrass

TREATMENTS.—Oats, variety 'Suregrain', were seeded into the coastal-bermudagrass sods of varying residual K status on October 26, 1966. The oats were top-dressed with 80 lb N/acre on March 8, 1967. The treatments from the potassium sources experiment were:

A. Control, no K applied
B. 100 lb of K in 1 application as KCl
C. 200 lb of K in 1 application as KCl
D. 200 lb of K in 1 application as potassium pyrophosphate
E. 200 lb of K in 1 application as K_2SO_4
F. 200 lb of K as KCl applied in 2 equal applications
G. 200 lb of K as KCl applied in 4 equal applications
H. 400 lb of K as KCl applied in 1 application
I. 400 lb of K as KCl applied in 2 equal applications
J. 400 lb of K as KCl applied in 4 equal applications
K. 800 lb of K applied as KCl in 1 application
L. 800 lb of K applied as K_2SO_4 in 1 application

Each treatment was replicated four times in a randomized block design. Potassium fertilizers were last applied in 1963.

Coastal-bermudagrass harvests were made on June 21, August 7, and September 7, 1967. Coastal bermudagrass was fertilized with 80 lb N/acre on June 22, August 7, and September 8, 1967. Oats were harvested and separated from coastal bermudagrass on June 21, 1967. There was no irrigation nor fertilization other than N. Ratings of oats and coastal bermudagrass for vigor and growth were made separately by two observers on June 21, 1969. These ratings were on the basis of 1=excellent growth and vigor, 2=very good, 3=good, 4=fair, 5=poor, 6=very poor.

RESEARCH RESULTS.—Accumulated coastal-bermudagrass yields and oat-grain and straw yields are presented in table 48, along with the growth and vigor ratings. Oat emergence and growth were generally quite excellent. No evidence for differential winter-killing as a function of residual K content was obtained. All plots froze back severely at least once during the winter months, but all recovered without apparent visual differences attributable to K sufficiency.

Response to residual K is quite evident in both coastal-bermudagrass and oat yields. The best oat yields occurred on the treatments of 800 lb K/acre, followed by 400 lb K, 200 lb K, and 100 lb K. Although the data have not been analyzed statistically, replicate values do suggest that the higher oat yield at 800 K as KCl may have significance. Residual K doubled coastal-bermudagrass yields and approximately doubled oat-grain yields. The results clearly indicate that oats can be successfully sod-seeded into dormant coastal bermudagrass. One problem associated with this variety of oats was that by the time the oats had matured, the coastal bermudagrass was growing up around the heads of the oats. Such a situation would make field combining impossible. However, the harvest of high-protein coastal bermudagrass with high-energy oats as haylage appears to have much merit.

Rye and Coastal Bermudagrass

TREATMENTS.—An established sod of coastal bermudagrass, growing in a Cecil sandy loam soil, was clipped to 2 inches for the first seeding of rye. After removing the coastal-bermudagrass clippings, rye (*Secale cereale* L.) was drilled into the sod in rows 10 inches apart with a grassland drill. In subsequent years, the fourth harvest of coastal bermudagrass was taken shortly before rye was seeded, making additional clipping unnecessary. The same land was used each year of the 3-year study. The experimental area was irrigated prior to seed-

TABLE 48.—*Influence of residual potassium on yields of coastal bermudagrass and sod-sown oats*

Original source and rate of K applied to coastal[1]	Accumulated coastal yield (tons/acre)	Oat-grain yield (bu/acre)	Oat-straw yield (tons/acre)	Ratings[2]	
				Oats	Coastal
0 K	3.07	20	0.34	4.7	3.9
100 K, 1 application	3.43	30	.37	4.7	3.1
200 K, 1 application	3.88	26	.48	3.5	2.5
200 K, K-pyrophosphate, 1 application	4.87	30	.64	2.7	2.0
200 K, K_2SO_4, 1 application	3.58	34	.57	3.4	2.4
200 K, 2 applications	3.54	32	.56	3.7	2.2
200 K, 4 applications	4.60	37	.66	3.1	2.5
400 K, 1 application	4.87	36	.71	2.2	2.1
400 K, 2 applications	5.21	36	.67	2.6	2.0
400 K, 4 applications	5.28	39	.78	2.6	2.2
800 K, 1 application	6.13	52	1.10	1.9	2.9
800 K, K_2SO_4, 1 application	6.21	39	.84	2.0	2.2

[1] Unless indicated otherwise, potassium was applied as KCl.

[2] Ratings are on the basis of 1=excellent growth and vigor, 2=very good, 3=good, 4=fair, 5=poor, 6=very poor.

ing rye to increase the probability of obtaining a good stand.

The experimental design was a modified split-split plot with three replications. The four main plots in 1963 (the experiments will be referred to by the year in which the coastal bermudagrass and rye were harvested rather than by the year in which the rye was seeded) were (1) rye seeded in coastal bermudagrass, (2) coastal bermudagrass disturbed, that is, the sod disturbed by the grain drill without planting any seed, and (3) coastal bermudagrass undisturbed, that is, the grain drill was never on these plots. The split-plot treatments consisted of 0, 40, 80, 120 and 160 lb N/acre added for the rye. The split-split plot treatments were 200 and 400 lb N/acre added for the coastal bermudagrass. The dates for fertilizer applications are given in table 49. Size of the split-split plots was 7 ft by 11 ft.

TABLE 49.—*Fertilizer application dates for coastal bermudagrass and for rye*

Cropping system and fertilizer treatment	1962–63	1963–64	1964–65
Coastal and rye, NA:[1]			
N for rye[2]	Oct. 23	Oct. 16	Oct. 28
Do	Feb. 25	Feb. 25	Feb. 23
P and K for rye	Oct. 23	Oct. 16	Oct. 28
N for coastal	June 3	June 10	June 3
Do	July 8	July 14	July 8
Do	...	Aug. 12	Aug. 9
P and K for coastal	June 3	June 10	June 3
Do	July 8	July 14	July 8
Coastal and rye, NB:[3]			
N for coastal	([4])	May 1	Apr. 29
Do	([4])	June 10	June 3
Do	([4])	July 14	July 8
Do	([4])	Aug. 12	Aug. 9
P and K for coastal	([4])	May 1	Apr. 29
Do	([4])	July 14	July 8
Conventional seedbed rye	([5])	([6])	([6])
Coastal only:			
N for coastal	Apr. 3	Apr. 15	Apr. 29
Do	July 8	June 10	June 3
Do	...	July 14	July 8
Do	...	Aug. 12	Aug. 9
P and K for coastal	Apr. 3	Apr. 15	Apr. 29
Do	July 8	July 14	July 8

[1] NA: nitrogen for coastal was added after the rye was harvested.

[2] Rates 33% and 67% of the annual were applied on the respective dates. The percentage of the annual rates of all other fertilizer for rye and for coastal was divided equally among the application dates.

[3] NB: nitrogen for coastal was added before the rye was harvested. Rye had the same fertilizer treatments as rye on the NA plots.

[4] These plots had sod-seeded oats in 1962–63, which the winter killed. Rye was seeded the last 2 years on these plots.

[5] There was no conventional seedbed rye in 1962–63.

[6] Same fertilizer treatment as for rye in coastal and rye.

Conventionally seeded rye plots were harvested in 1964 and 1965 from an adjacent land area with 0, 40, 80, and 160 lb N/acre added for the rye (table 49). All plots of coastal bermudagrass received 156 and 568 lb P_2O_5 and K_2O per acre per year, respectively. All rye plots received 52 and 189 lb P_2O_5 and K_2O per acre per year, respectively. One-third of the annual rate of N and all the P and K for rye were added near the drill row when the rye was seeded. All other fertilizer was surface broadcast.

Rye was clipped near the top of the coastal bermudagrass and the coastal bermudagrass and rye-stubble mixture was then clipped 2 inches above the soil surface. The coastal bermudagrass was hand separated from the rye stubble to determine the amount of coastal-bermudagrass growth in the mature rye crop. Seeding and harvesting dates are given in table 50. Rye yields are reported on the basis of 15.5 percent moisture and coastal-bermudagrass yields were determined after ovendrying at 57° C.

RESEARCH RESULTS.—(*1*) *Yields for disturbed and undisturbed coastal bermudagrass only.*—Yields for disturbed and undisturbed coastal-bermudagrass-only plots, with two rates of N, are given in table 51. Yields were significantly higher with 400 lb N/acre than with 200. The 3-year-average yields, across rates of N, are 6.0 and 6.4 tons per acre for disturbed and undisturbed, respectively (significant at the 5-percent level by the *F*-test). Undisturbed plots yielded about 0.8 ton per

TABLE 50.—*Dates rye was seeded and harvest dates for coastal bermudagrass and for rye*

Operation	1962–63	1963–64	1964–65
Seed rye	Oct. 23	Oct. 16	Oct. 28
Harvested rye	June 3	June 10	June 3
Harvested coastal	June 3	June 10	June 3
Do	July 8	July 14	July 8
Do	Aug. 9	Aug. 12	Aug. 9
Do	Oct. 11	Oct. 6	Sept. 27

acre per year more than the disturbed plots at 200 lb N/acre, but there was little yield difference between disturbed and undisturbed at 400 lb N/acre. The higher N level resulted in quicker repair of sod damage in the spring, thereby accounting for lack of yield difference between disturbed and undisturbed at the high N level.

Some soil and sod disturbance occurred from pulling the grassland drill through the sod in the fall. The shoes on the drill were only about 2 inches wide and were preceded through the sod by a colter. With such little disturbance, large yield differences between the disturbed and undisturbed coastal-bermudagrass-only plots should not be expected.

(*2*) *Coastal-bermudagrass yields with coastal bermudagrass only and coastal bermudagrass and rye.*—In 1963, coastal-bermudagrass yields for coastal bermudagrass and rye were lower than for coastal bermudagrass only for the first three harvests. At the first harvest, coastal-bermudagrass yield with coastal bermudagrass and rye was only 40 percent of the yield obtained with coastal bermudagrass only. However, cumulative coastal-bermudagrass yields for the year were not significantly different between coastal bermudagrass and rye and coastal bermudagrass only.

The low yield of first-harvest coastal bermudagrass from the coastal bermudagrass and rye system might have been caused by N deficiency, since N applications prior to the first harvest of coastal bermudagrass had been timed for the benefit of the rye. Thus, no N had been added specifically for the coastal bermudagrass on the coastal bermudagrass and rye plots prior to harvest of rye and coastal bermudagrass on June 3, 1963. On the other hand, N had been added to the coastal-bermudagrass-only plots on April 3. In 1964 and 1965, N was added for coastal bermudagrass before (NB) and after (NA) the rye was harvested.

Yields of coastal bermudagrass for coastal bermudagrass only were higher than for coastal bermudagrass and rye in 1964. However, there was little yield difference between coastal bermudagrass only and coastal bermudagrass and rye in 1965. Adding N for coastal bermudagrass prior to rye harvest (NB) gave higher first-harvest yields for coastal bermudagrass than when N was added after (NA) rye harvest, but this difference attained statistical significance only in 1965. In 1965, this yield difference was reflected in season cumulative yield, whereas the NA and NB cumulative yield curves intersected between the second and third harvest in 1964. The 3-year-average coastal-

TABLE 51.—*Yield of coastal bermudagrass with and without rye overseeded and at various rates of nitrogen*

Cropping system	N for rye (lb/acre)	N for coastal (lb/acre)	Rye yield (bu/acre)			Coastal-bermudagrass yield (tons/acre)		
			1963	1964	1965	1963	1964	1965
Coastal and rye	0	200	[1]9.8	10.8	4.2	6.1	5.9	5.8
Do	0	400	...	19.5	5.6	7.0	7.4	7.6
Do	40	200	17.4	24.8	8.8	5.9	5.7	5.3
Do	40	400	...	33.6	13.6	7.0	7.0	6.9
Do	80	200	30.4	36.7	15.0	5.5	5.2	5.3
Do	80	400	...	39.1	18.7	7.0	6.4	6.4
Do	120	200	33.7	39.0	26.2	6.2	5.4	5.1
Do	120	400	...	40.7	27.2	6.9	5.9	6.0
Do	160	200	40.1	44.0	24.8	6.3	5.4	5.0
Do	160	400	...	38.9	22.3	7.0	5.9	5.6
Coastal-only, disturbed	...	200	...	...	...	4.6	5.4	4.7
Do	...	400	...	...	...	7.2	8.0	6.3
Coastal-only, undisturbed	...	200	...	...	...	5.4	6.4	5.4
Do	...	400	...	...	...	6.6	8.0	6.6

[1] The 200 and 400 N rates were not applied to the coastal ahead of the 1963 rye harvest.

bermudagrass yields were 6.08 and 6.07 tons per acre per year for coastal bermudagrass only and all coastal bermudagrass and rye plots, respectively.

(*3*) *Rye-grain yields with rye only and coastal bermudagrass and rye.*—The grain yields of sod-seeded rye (coastal bermudagrass and rye) compared to conventional seedbed rye (rye only) were not significantly different in either 1964 or 1965 (as determined by *t*-tests, where the probability exceeded 50 percent in both years). There was a trend in both years toward higher yields of rye grain in sod-seeded culture than in conventional culture at the higher N levels, but this trend was not statistically significant at the 5-percent level. Average grain yields for all rates of N in 1964 were 32.4 and 30.2 bushels per acre for coastal bermudagrass and rye and rye only, respectively. In 1965, average yields were 16.4 and 15.3 bu/acre for coastal bermudagrass and rye and rye only, respectively.

Rye-grain yields were considerably lower in 1965 than in 1964, which was probably associated with dry conditions decreasing the seed set and filling in 1965.

(*4*) *Rye grain and coastal-bermudagrass yields with coastal bermudagrass and rye.*—Rye-grain yields increased as the rate of N for rye increased, with the exception of the highest rate of N in 1964 and 1965. Rye yields for 1964 and 1965 were higher with 400 lb N/acre for coastal bermudagrass than with 200 lb N/acre for coastal bermudagrass with the exception of the highest N rate to the rye. Residual N at the higher N rate for coastal bermudagrass was the probable cause for the increased rye yields.

Coastal-bermudagrass yields in 1963 were affected little by the rate of N added for rye. In 1964 and 1965, coastal-bermudagrass yields were reduced by adding N for rye. The yield reduction was relatively greater with 400 lb N/acre for coastal bermudagrass than with 200 lb N/acre for coastal bermudagrass.

(*5*) *Early growth of coastal bermudagrass with coastal bermudagrass and rye.*—The number of coastal-bermudagrass shoots in coastal bermudagrass and rye on April 12 decreased as the rate of N added for rye increased to 80 lb/acre. At higher rates of N there was no further decrease in the number of coastal-bermudagrass shoots. First-harvest coastal-bermudagrass yields decreased as the rate of N for rye increased, and this decrease occurred over all rates of N for rye.

Welch et al. (*18*) reported that these effects on the coastal bermudagrass probably resulted from differences in light intensity, soil temperature, and soil water. The relative light intensity with coastal bermudagrass and rye decreased from March to April as the rye grew rapidly. The increase in relative light intensity occurring from April to May was associated with leaf senescence of the rye.

Plots of coastal bermudagrass and rye that had received 160 lb N/acre for the rye had a lower relative light intensity than the plots receiving 40 lb N/acre because of more vegetative growth and consequently more shading. Low light intensity may have been partially responsible for the low first-harvest coastal-bermudagrass yields with high N for rye.

Copper-constantan thermocouples and a potentiometer pyrometer were used to measure soil temperature at the 2-inch depth in 1963. After March 17, the soil temperature was higher for the coastal-bermudagrass-only plots and the coastal bermudagrass and rye plots that received 40 lb N/acre for the rye than for the coastal bermudagrass and rye plots that received 160 N/acre. The higher soil temperature on the low-N plots was expected because of the higher light intensity on these plots compared to high-N coastal bermudagrass and rye plots. The higher soil temperature, with low N compared to high N, may result in coastal-bermudagrass dormancy being broken earlier in the spring with low N than with high N.

Gravimetric soil-water samples were taken at various times and soil depths from the coastal bermudagrass and rye plots before rye harvest in 1965. The percentage of soil water at the 3- to 6-inch depth was less with 160 lb N/acre added for rye than with no N added. This reduction in soil water with added N generally occurred to a soil depth of 21 inches.

CORN IN TALL FESCUE

TREATMENTS.—Corn, 'Pioneer 8185', was planted in tall-fescue sod on Cecil sandy loam soil, class II land in 1969, 1970, and 1971. Treatments and corresponding results were

varied from year to year, and are presented by year.

1969.—Corn was planted in rows 40 inches apart on plowed land following corn in previous years and on fescue sod without tillage (no-till). Fertilizer was applied uniformly with 12–137–72 lb N–P_2O_5–K_2O per acre under the row at planting and 120 lb N/acre to the corn about 40 days after planting. Irrigation treatments included: (1) no irrigation, (2) irrigate at 5 bars suction, and (3) irrigate at 1 bar suction, with three replications of each treatment. The corn on plowed land was cultivated for weed control, but the corn in fescue received no cultivation or any form of grass or weed suppression. Electrical-resistance blocks were placed in the soil at depths of 2, 4, 9, 15, 21, and 30 inches. Irrigation water was applied with sprinklers to fully replenish the top 24 inches when the top 12 inches reached the prescribed suction.

1970.—Corn was no-till planted in rows 20 inches apart in fescue on April 28. The sod was clipped April 27 to less than 2 inches above ground level and treated with atrazine [2-chloro-4-(ethylamino)-6-(isopropylamino)-*s*-triazine] and paraquat (1,1′-dimethyl-4,4′-bipyridinium ion) with the following rates of active ingredient per acre:

Treatment No.	*Atrazine* (lb/acre)	*Paraquat* (lb, acre)
1	0	0
2	2	0
3	2	¼

The atrazine and paraquat solutions were mixed in a liquid nitrogen solution and sprayed onto the sod to give 130 lb N/acre with the prescribed amounts of the herbicides. The 0-herbicide treatment also received 130 lb N/acre. Phosphorus and potash were broadcast on the sod to give 160 lb P_2O_5 and 160 lb K_2O per acre. A starter fertilizer applied under the row as the corn was planted included 40 lb P_2O_5 and 40 lb K_2O per acre. Nitrogen variables included an additional 100 and 300 lb N/acre to give N rates of 130, 230, and 430 lb/acre. The irrigation variables were on whole plots, herbicides on split plots, and N levels on split-split plots with three replications. A second study of fertilizer variables with four replications included poultry-house litter at rates of 2.5, 5, 10, and 20 tons per acre and 430 lb N/acre on the herbicide treatments 1 and 3 above. This litter was applied 1 day after the corn was planted. A plant population variable of 15,000 and 30,000 plants per acre was superimposed on all treatments in both these studies. Irrigation treatments included rainfall only and rainfall plus irrigation. Water was added with sprinklers when electrical-resistance blocks showed that 50 percent of the available water was used from the soil profile to a 24-inch depth. There was no tillage or weed control in the corn.

1971.—Treatments were similar to those in 1970 except that all plots were planted for 30,000 plants per acre, all areas were irrigated as needed, and the herbicide variables included 0+0, 0+¼, ½+¼, 1+0, 1+¼, and 2+½ lb active ingredient of atrazine and paraquat per acre. Fertility treatments were the same as in 1970. Corn was planted May 3, 1 day after the poultry litter was applied.

RESEARCH RESULTS.—*1969.*—Rainfall was adequate in June, deficient with less than a 1 inch total in six small showers in July and early August, and adequate for corn production in late August. Soil-water records showed that the nonirrigated corn exhausted all available soil water to a depth greater than 24 inches from about July 10 until rains started August 12. Soil water was adequate in the 0- to 24-inch soil zone at all times with the 1- and 5-bar irrigation treatments, with little or no effective difference between these treatments. Some corn plants died in the nonirrigated plots due to the drought. Yields were increased with irrigation in both the clean-till and no-till corn (table 52). The total failure of the unirrigated, no-till corn and some yield in the cultivated corn showed that the water requirement for the corn and grass was higher than for clean-tilled corn. The reduced yield for the no-till corn with irrigation from the clean-till corn (72.5 versus 134.1 bu/acre) suggests that the competition

TABLE 52.—*Yield of clean-till versus no-till corn in 1969*

	Plants per plot		Grain (bu/acre)		Stover (lb/acre)	
	Clean-till	No-till	Clean-till	No-till	Clean-till	No-till
Irrigated	281	310	134.1	72.5	5771	2335
Unirrigated	274	167	26.1	.6	3641	189

for nutrients and the nutrient requirement of corn and grass were higher and still important factors, even if water was not limiting.

1970.—There was a complete kill of fescue sod with the 2+¼ atrazine+paraquat treatment and about an 80 percent kill with the 2+0 treatment. An excellent stand of corn was obtained in both population treatments, with actual rates of germination being near 23,000 and 30,000 plants per acre. Rainfall was inadequate in May, June, and part of July, and severe drought conditions developed on the nonirrigated treatments. Soil-water records showed an adequate level of soil water at all times on the irrigated treatments. Many plants died in the unirrigated plots at all fertility levels, a greater number on the live sod (0+0 atrazine+paraquat) than with the stunted and killed sod. Also, the rate of 20 tons of poultry litter per acre caused many corn plants to die in the germination stage (table 53). Corn-grain yields were low without irrigation, ranging from 0 on the live sod to 21.2 bu/acre on the killed sod. With irrigation, yields ranged from 1.5 bu/acre on live sod with 130 lb N/acre to 159.7 bu/acre on killed sod with 430 lb N/acre. There was little or no increase in yield with the killed sod over the stunted sod with irrigation and inorganic nitrogen only. With poultry litter, the yield for the 30,000 plants per acre increased from 78.7 bu/acre with 2.5 tons per acre to 160.6 bu/acre with 10 tons per acre on live sod, and from 152.9 bu/acre with 2.5 tons per acre to 179.8 bu/acre with 5 tons per acre on killed sod. Additional litter beyond these rates caused reductions in stand on the live and killed sod, thereby giving reduced yields (table 53). Subsequent studies at SPCRC have shown that rates of poultry litter in excess of 10 tons per acre caused excessive stand loss if corn is planted within 8 days of litter application. After 8 days, the percentage of emergence of corn was unaffected by 20 tons of poultry litter per acre.[6]

Corn yields in a nearby area where corn was planted after fescue sod was turned, the land disked, and the corn cultivated in conventional manner, with the same fertility as the 430 lb N/acre, were 99.4 and 165.1 bu/acre for the 15,000 and 30,000 plant population treatments. Reestablishing the fescue after corn was most successful where seed were drilled on a well prepared and fertilized seedbed.

1971.—The unirrigated and 15,000 plant per acre variables were not repeated in 1971 so that six levels of atrazine+paraquat could be

[6] C. R. Campbell, 1973, Establishment and growth of corn in chicken litter-fertilized tall fescue, M.S. thesis, University of Georgia.

TABLE 53.—*Number of plants and yield of no-till corn in 1970*

Fertility treatment: N (lb/acre) + poultry litter (tons/acre)	Anticipated plants per acre (×1,000)	Actual plants (×1,000) per acre for sod treatment[1]						Grain yield (bu/acre) for sod treatment[1]					
		Unirrigated			Irrigated			Unirrigated			Irrigated		
		0+0	2+0	2+¼	0+0	2+0	2+¼	0+0	2+0	2+¼	0+0	2+0	2+¼
130 N	15	11.3	26.1	23.5	13.0	17.4	22.6	0	10.0	15.0	1.5	52.5	56.8
130 N	30	11.3	27.0	23.6	13.9	29.6	35.7	0	11.6	19.8	2.2	68.4	69.6
230 N	15	7.8	25.3	23.5	17.4	21.8	23.5	.7	2.7	17.5	14.2	88.2	100.2
230 N	30	16.5	24.4	29.6	27.8	34.0	36.5	.4	4.5	21.2	16.7	127.8	137.6
430 N	15	7.0	22.6	21.8	22.6	19.2	22.6	.3	2.1	11.9	55.3	128.1	116.4
430 N	30	9.6	21.8	27.9	25.3	34.0	25.3	.2	5.4	16.6	72.1	156.0	159.7
130+2.5	15	...	...	...	16.5	...	20.9	...	...	...	54.0	...	105.0
130+2.5	30	...	...	...	28.7	...	35.7	...	...	...	78.7	...	152.9
130+5	15	...	...	...	14.8	...	21.8	...	...	...	84.9	...	130.7
130+5	30	...	...	...	31.3	...	35.7	...	...	...	132.1	...	179.8
130+10	15	...	...	...	14.8	...	16.5	...	...	...	90.0	...	89.4
130+10	30	...	...	...	29.6	...	29.6	...	...	...	160.6	...	148.5
130+20	15	...	...	...	4.4	...	11.3	...	...	...	35.7	...	66.8
130+20	30	...	...	...	11.3	...	12.2	...	...	...	90.4	...	72.7
430 N	15	...	...	...	18.3	...	20.0	...	...	...	55.0	...	119.9
430 N	30	...	...	...	27.0	...	33.9	...	...	...	70.9	...	153.7

[1] Lb/acre active ingredient of atrazine+paraquat.

TABLE 54.—*Plant population on May 20 and October 14, 1971, with no-till corn in fescue*

[Plants ×1,000 per acre]

Nitrogen (lb/acre) + poultry litter (tons/acre)	Atrazine+paraquat (lb/acre)											
	0+0		0+¼		½+¼		1+0		1+¼		2+½	
	May 20	Oct. 14	May 20	Oct. 14	May 20	Oct. 14	May 20	Oct. 14	May 20	Oct. 14	May 20	Oct. 14
130	24.8	8.3	26.1	13.5	31.3	23.5	33.3	19.6	37.2	24.8	35.2	31.3
230	24.8	9.1	28.7	18.7	30.6	25.6	32.0	25.6	33.9	28.7	30.6	31.7
430	21.5	8.7	27.4	21.7	30.6	27.4	29.3	23.5	30.0	29.1	35.9	31.7
130+2.5	23.5	9.6	...	...	...	...	...	...	...	...	28.0	26.5
130+5	17.0	11.3	...	...	...	...	...	...	...	...	30.6	28.7
130+10	[1]11.7	11.3	...	...	...	...	...	...	...	...	[1]13.0	23.9
130+20	[1]0	7.4	...	...	...	...	...	...	...	...	[1]0	17.4
430	21.5	6.5	...	...	...	...	...	...	...	...	30.6	28.7

[1] Replanted May 21.

TABLE 55.—*Average plant-nutrient concentration in poultry litter applied and calculated amount supplied, 1970 and 1971*

Plant nutrient	Nutrient concentration[1]		Nutrient supplied (lb/acre) at poultry-litter rate of—							
			2.5 tons/acre		5.0 tons/acre		10.0 tons/acre		20.0 tons/acre	
	1970	1971	1970	1971	1970	1971	1970	1971	1970	1971
N	5.10%	3.50%	255	181	510	360	1,020	720	2,040	1,441
P[2]	1.69%	1.56%	85	80	169	161	338	321	676	642
K[3]	2.28%	1.98%	114	102	228	204	456	407	912	815
Ca	1.99%	1.71%	100	88	199	176	398	352	796	704
Mg	.47%	.43%	24	22	47	44	94	88	188	177
S	([4])	.401%	([4])	21	([4])	42	([4])	83	([4])	165
Mn	357	260	1.8	1.3	3.6	2.7	7.1	5.4	14.2	10.7
Fe	1,062	663	5.3	3.4	10.6	6.8	21.2	13.6	42.5	27.3
B	43	41	.2	.2	.4	.4	.9	.8	1.7	1.7
Cu	51	79	.3	.4	.5	.8	1.0	1.6	2.0	3.3
Zn	345	334	1.7	1.7	3.5	3.4	6.9	6.9	13.8	13.8
Al	2,287	631	11.4	3.3	22.9	6.5	45.7	13.0	91.5	26.0
Mo	9.0	5.1	.1	.03	.1	.05	.2	.1	.4	.2
Sr	29	44	.2	.2	.3	.5	.6	.9	1.2	1.8
Ba	23	12	.1	.1	.2	.1	.5	.3	.9	.5
Na	3,400	2,707	17.0	13.9	34.0	27.9	68.0	55.7	136.0	111.4

[1] Dry-matter basis. Values not followed by a percent sign represent micrograms per gram.
[2] $P \times 2.29 = P_2O_5$.
[3] $K \times 1.20 = K_2O$.
[4] Not analyzed for sulfur in 1970.

compared on the fescue sod. These levels were 0+0, 0+¼, ½+¼, 1+0, 1+¼, and 2+½ lb active ingredient of atrazine+paraquat per acre.

Conditions for corn germination were excellent after the corn was planted May 3. After germination was complete, stand counts on May 20 showed that the plant population was lower in the live and slightly stunted sod than in the more severely stunted and killed sod, that level of N had little effect on germination, and that increased rates of poultry litter severely reduced germination (table 54). Stand counts at harvest on October 14 showed additional losses on all fertility treatments in the live and stunted-sod treatments.

Nutrient analyses of the poultry litter in 1970 and 1971 showed that adequate to high levels of N, P, and K were applied (table 55). Much of the N was lost through volatilization, and the odor of ammonia was strong for several days after the litter was applied. Analysis of

TABLE 56.—*Plant-nutrient composition of corn ear leaf taken at tasseling stage, 1971*[1]

Atrazine+paraquat (lb/acre)	Nitrogen (lb/acre) + poultry litter (tons/acre)	Plant nutrient									
		N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Mn (μg/g)	Fe (μg/g)	Cu (μg/g)	Zn (μg/g)	B (μg/g)
0+0	130	2.40	0.48	2.26	0.18	0.10	47	74	18	40	6
	230	2.40	.42	2.53	.16	.09	61	69	14	29	8
	430	2.80	.38	3.04	.20	.05	127	79	14	30	7
0+¼	130	1.90	.36	2.05	.36	.10	46	64	11	21	7
	230	2.20	.34	2.24	.22	.07	62	66	11	26	8
	430	3.00	.36	2.46	.31	.13	125	87	12	29	5
½+¼	130	2.00	.42	2.24	.22	.08	68	70	11	27	6
	230	2.60	.27	2.01	.37	.15	85	85	12	32	5
	430	3.00	.34	2.16	.36	.13	160	90	13	30	7
1+0	130	2.40	.35	2.63	.27	.10	58	71	11	24	5
	230	2.60	.34	2.49	.26	.08	75	76	11	26	6
	430	3.00	.32	2.63	.27	.10	128	81	11	28	5
1+¼	130	2.30	.36	2.31	.32	.11	68	80	11	26	7
	230	2.80	.29	2.52	.32	.10	76	87	16	26	7
	430	3.20	.32	2.64	.36	.11	123	93	13	26	6
2+½	130	3.00	.33	2.53	.32	.07	95	84	16	31	8
	230	3.10	.35	2.47	.29	.08	129	90	14	32	8
	430	3.20	.36	2.49	.26	.06	156	88	17	33	8
0+0	130+2.5	2.80	.39	3.38	.29	.12	104	88	13	26	6
	130+5	3.10	.40	3.39	.35	.14	101	109	14	28	8
	130+10	3.10	.42	3.28	.32	.11	306	100	12	34	9
	130+20	3.40	.49	3.25	.30	.11	610	110	12	45	11
	430	3.10	.34	2.84	.26	.07	117	88	12	32	7
2+½	130+2.5	3.10	.39	2.89	.35	.08	109	102	15	30	8
	130+5	3.10	.43	2.46	.34	.10	145	101	19	43	10
	130+10	3.20	.45	2.92	.31	.11	207	102	16	37	12
	130+20	3.30	.50	3.34	.25	.08	342	99	11	32	10
	430	3.20	.41	3.11	.34	.09	152	111	17	32	8

[1] Plant ear-leaf analyses conducted by Soil and Plant Tissue Testing Laboratory, University of Georgia, Athens, Ga.

plant nutrients in the tissue of the ear leaf at tasseling stage showed good to high levels of the essential plant nutrients for all fertility and herbicide treatments (table 56). One possible exception appeared to be magnesium levels in ear-leaf tissues, which appeared to be marginal (0.10 percent Mg is considered a sufficient concentration for optimum growth of corn).

Corn yields ranged from 4.2 bu/acre in the live sod (0+0 atrazine+paraquat) and 130 lb N/acre to 191.6 bu/acre with 230 lb N/acre, 198.4 bu/acre with 130 lb N+5 tons poultry litter per acre, and 208.6 bu/acre with 430 lb N/acre, all on killed sod (table 57). No level of N alone gave satisfactory yields on the live sod, but the 130 lb N+5 tons poultry litter per acre gave 83.3 bu/acre on live sod. Yields generally increased with reduced growth of sod at all N levels.

Tall fescue present in the live sod (table 58)

TABLE 57.—*Yield of no-till corn in fescue, 1971*

[Bushels per acre]

Nitrogen (lb/acre) + poultry litter (tons/acre)	Atrazine+paraquat (lb/acre)					
	0+0	0+¼	½+¼	1+0	1+¼	2+½
130	4.2	12.7	42.1	37.7	77.4	154.5
230	29.1	52.8	108.6	83.0	131.7	191.6
430	36.2	89.9	105.3	112.4	143.8	184.0
130+2.5	55.1	...	...	...	...	181.4
130+5	83.3	...	...	...	...	198.4
130+10	82.1	...	...	...	...	173.8
130+20	68.3	...	...	...	...	120.8
430	26.0	...	...	...	...	208.6

TABLE 58.—*Tall fescue present in no-till corn with live sod treatment*

Sod treatment		Fescue (tons/acre)						
Nitrogen (lb/acre)	Poultry litter (tons/acre)	1970, Sept. 14	1971					
			May 17	June 4	June 25	July 15	Aug. 4	Oct. 29
130	2.5	1.00	1.47	2.56	2.20	2.48	3.39	2.96
130	5.0	.98	1.13	2.82	2.64	3.30	3.74	2.73
130	10	1.08	.67	2.26	3.25	3.28	3.53	2.62
130	20	1.55	.36	1.74	2.27	3.22	3.62	3.17
430	0	1.12	1.28	2.16	2.30	3.17	4.20	2.75

TABLE 59.—*Postulated nitrogen removal in corn and fescue removed from killed and live sod treatment receiving 130 lb N/acre plus 5.0 tons poultry litter per acre (1971)*

Sod treatment	Crop component	Yield (lb/acre)	N[1] (%)	N removal (lb/acre)	Percentage removed	
					Total N[2]	Adjusted[3]
Live	grain	4,584	1.52	69.7	...	...
Do	stover	3,562	.73	26.0	...	...
Do	fescue	5,452	2.0	109.0	...	...
Total N removal				204.8	43	55
Killed	grain	10,912	1.52	165.9	...	...
Do	stover	7,914	.73	57.6	...	...
Total N removal				223.5	47	60
Do	residue	9,944	1.2	119.3	...	...
Total N accounted for				342.8	71	92

[1] N percentage figures were obtainted from unpublished data from similar experiments at the Southern Piedmont Conservation Research Center. The N percentages used were the more conservative of those available.

[2] Based on total N input of 330 lb from NH_4NO_3 and 880 lb from poultry litter.

[3] Based on total N input 330 lb from NH_4NO_3 plus 70% of total N in poultry litter. Volatilization losses of 30% were assumed.

after corn harvest in 1970 was slightly higher with the highest rate of poultry litter than with any other treatments. In 1971, the high rate of poultry litter (20 tons per acre) reduced the growth of the tall fescue in May and June, as compared to the other treatments, but by July the grass had fully recovered. The yields on October 29, 1971, after corn harvest, showed no significant differences in tall fescue present from the litter treatments. The tall fescue was not harvested over the entire summer period and had developed a dense canopy. Most of the leaves were fully mature, some were dead, and some probably had decomposed, accounting for the fluctuating values at the last two measurements. The data in table 58 reflect forage present at the different times, but not growth rates of the tall fescue.

This method will give excellent runoff and erosion control and produce needed grain while utilizing a waste product with minimum environmental hazard with a moderate rate of litter application. This system appears successful from the standpoint of using poultry litter on rolling, erosion-susceptible land for corn production with minimum soil and runoff water loss. Plant nutrient losses to surface and ground water were not evaluated in these experiments. Nitrogen removals in the harvested crop were calculated for the application of 5 tons poultry litter per acre in 1971 to killed and live sod. These indicate substantial nitrogen removals in the harvested crops (43 to 47 percent of total N applied) (table 59). Volatilization losses of N as ammonia from the surface applications of poultry litter were not measured in these experiments, but several published reports show that NH_3–N losses may be appreciable from

surface applications of manure (*5, 16*). Studies at this location indicate that the total N in surface-applied poultry litter was only 50 to 60 percent as effective in producing fescue yield as N from NH_4NO_3 (Southern Piedmont Conservation Research Center, 1971, unpublished data). If a 30 percent N loss due to volatilization of NH_3 is assumed, the postulated N removals in relation to effective N inputs are good. If the residue remaining on the killed-sod treatment contained 1.2 percent N, then 92 percent of the N was accounted for in the harvested crop plus surface residue. Although these calculations are speculative, since they use conservative N values from other experiments, they do suggest that potential N recoveries are good and that N inputs may not be excessive from the crop utilization point of view.

Poultry litter and spreading equipment are readily available to many farms where tall fescue is grown. Herbicides, power sprayers, and no-till planters are available commercially. Irrigation is the major element lacking in the capability to produce high yields of corn by the no-till system in the southern Piedmont and similar areas. Favorable topography and an excess of rainfall over evapotranspiration part of each year are conducive to the development of water resources for this needed irrigation capability.

CONCLUSIONS

This publication summarizes 20 years of research on the effects of cropping systems on productivity and soil erosion potential for the southern Piedmont physiographic region. This research has been the basis for many of the improved soil and land resource conservation practices in action in the region. The following conclusions are made from the various studies reported herein.

1. Sod crops controlled both runoff and soil loss on sloping land. This beneficial effect extended through the first row crop in cropping systems where row crops followed sod crops on the land.

2. Sod crops improve soil productivity.

(a) Corn yields were higher from corn after vetch, rye, alfalfa, and grasses than corn after corn. This increase in productivity lasted 2 to 4 years after the sod was plowed under.

(b) There was no advantage in applying N to corn after vetch or alfalfa. The fixed nitrogen gave yield responses comparable or superior to yields obtained from 80 to 120 lb N per acre per year under the cultural practices employed.

(c) Yield of corn following tall fescue was highest the first year after sod, and declined with each succeeding year of corn. Conversely, the yield of corn following tall fescue increased with age of the fescue through 2 to 3 years. 'Kentucky-31' tall fescue was demonstrated to be effective in conservation of nitrogen.

(d) Where 10-year old sericea lespedeza that had received little or no fertilizer was plowed out, corn yields were increased most by a complete fertilization with N, P, and K. Lister planting or conventional turnplowing made little or no difference on corn yield where fertilizer and soil water were adequate.

(e) The production of good corn yields without irrigation was dependent on the occurrence of effective rainfall during the 9th, 10th, 11th, and 12th weeks after plant emergence. Lack of soil water often dominates other management effects on yields, suggesting that production of dependable high yields of corn requires irrigation.

(f) Under good soil management practices including balanced fertilization, there was little or no effect of land slope on corn yields the first year of corn following fescue during any of 5 years of record at the most of seven sites studied in the southern Piedmont physiographic region.

(g) No-till corn in fescue sod produced excellent yields when nutrient and water requirements were met. No-till corn has wide adaptation on sloping lands because of the beneficial effects of mulch and sod on infiltration, reduced runoff, and consequently reduced soil erosion and nutrient losses.

3. Coastal bermudagrass was at least 50 percent superior to common bermudagrass for forage production. Crimson clover overseeded on bermudagrass extended the forage production period and slightly increased total forage yields at all levels of nitrogen input. Total production of clover and grass without N fertilizer was similar to that obtained with 100 lb N per acre to bermudagrass alone. Nitrogen fertilizer was required to realize the growth potential of the bermudagrasses.

4. Bermudagrass responded to N, P, and K

fertilizer with the greatest response occurring from a balanced combination of N–P–K. A 4–1–2 ratio of $N–P_2O_5–K_2O$ appeared best for coastal bermudagrass. Concentrations of K in coastal bermudagrass above which there was little yield response to added fertilizer potassium were 1.4 to 1.5 percent K.

5. Coastal-bermudagrass yield was increased by irrigation, and by increasing intervals between clipping and fertility level. Water-use efficiency was increased by those factors such as N and longer clipping intervals that increased yield. For optimum water-use efficiency and fertilizer-use efficiency and yield of quality forage, a clipping interval of about 4 weeks is recommended. Phosphorus and potassium fertilizer increased N recovery at high rates of N fertilization.

6. Coastal bermudagrass was tolerant to a wide range of soil acidity. Response to liming occurred when soil pH was 5.0 or below. However, liming is essential in bermudagrass production to neutralize acidity from commonly applied N fertilizers (those that contain ammonium, urea). Root-growth response to liming and soil pH was relatively small with coastal bermudagrass. Alfalfa, on the other hand, requires a strong liming program (higher soil pH) for establishing and maintaining a healthy, strong root system.

7. Tall fescue can be successfully established in coastal bermudagrass by fall sod-seeding techniques. This combination can be maintained by judicious management of nitrogen fertilization and clipping (grazing) management. High nitrogen and close clipping promote coastal bermudagrass while low N and high clipping promote the fescue.

8. Cropping systems that include sod crops in sequence with row crops are excellent soil and water management systems that (a) increase crop yields, (b) increase efficiency of water and fertilizer use, (c) reduce water and soil loss from the land, and (d) provide environmental benefits through smaller losses of sediment and agricultural chemicals from the land.

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APPENDIX.—ADDITIONAL DATA

TABLE A–1.—*Rainfall by days in June and July, 1958–64*

[Inches]

Day	1958		1959		1960		1961		1962		1963		1964	
	June	July	June	July	June	July	June	July	June	July	June	July	June	July
1	0.82	...	0.57	1.82	...	0.13	...	...	1.99	...	...	...	0.82	...
2	.05	...	.49	...	0.05	...	...	...	.29	...	...	...	...	2.56
3	...	...	...	...	...	...	...	...	...	...	...	...	...	.17
4	...	0.14	...	...	...	...	...	...	...	0.29	...	...	...	...
5	...	.04	...	...	.12	...	...	...	.31	...	...	...	...	...
6	...	...	.07	...	.41	.42	...	...	...	.11	...	0.40	.08	...
7	...	.04	...	...	.01	.06	...	1.38	...	.17	...	...	...	...
8	...	.86	...	...	...	...	...	...	.05	.76	0.20	...	...	.05
9	.17	1.69	...	...	...	...	...	...	...	.02	...	...	...	...
10	...	.84	...	.03	...	1.46	0.05	...	.07	...	...	...	...	.11
11	...	.02	...	.51	...	...	1.39	.40	.44	...	...	...	...	...
12	...	.04	...	...	...	...	...	1.17	.16	.09	...	...	...	.88
13	...	...	...	...	...	...	...	2.36	...	...	...	...	.11	1.38
14	...	.46	...	...	.35	...	.32	...	...	...	...	.09	...	...
15	.16	.02	...	.05	...	...	.93	.22	...	...	...	...	...	...
16	...	...	...	.08	...	...	...	...	...	...	1.99	.29	...	...
17	...	...	...	.17	...	...	...	1.20	...	...	1.23	...	...	.02
18	...	...	...	...	...	...	...	.37	...	.47	1.15	.03	...	4.40
19	...	...	...	1.29	...	...	...	.33	...	...	.48	...	...	.04
20	...	...	...	1.55	...	...	.54	...	...	...	.24	.49	...	3.52
21	.60	.07	.28	.06	.27	...	1.27	...	...	...	.48	...	...	.36
22	...	.22	...	.28	...	1.24	...	1.04	...	...	.30	...	...	1.24
23	...	.02	...	...	...	.25	.67	...	...	...	.13	.15	1.54	.03
24	...	.38	.12	...	...	.03	.10	...	...	.06	.62	...	...	.06
25	...	...	.27	...	.56	...	...	...	...	.36	.03	.32	...	...
26	.28	...	...	...	...	.20	.78	...	2.10	...	4.50	.06	.35	.03
27	...	.30	...	...	...	.05	.11	...	...	...	.20	...	...	...
28	...	...	...	...	...	.90	...	...	.20	.07	.26	...	...	...
29	...	...	...	...	...	...	...	...	...	...	.74	...	...	...
30	...	.10	...	...	...	.04	...	...	...	.23	...	1.17	...	...
Total	2.08	5.24	1.80	5.84	1.77	4.78	6.16	8.47	5.61	2.63	12.55	3.00	3.56	14.85
Mean	3.88	5.00	3.88	5.00	3.88	5.00	3.88	5.00	3.88	5.00	3.88	5.00	3.88	5.00

TABLE A–2.—*Yields of perennial forages by years with different levels of nitrogen applied each year*

[Tons per acre, ovendry basis]

Forage	Years	Nitrogen applied (lb/acre)			
		0	80	160	320
Alfalfa	1958	3.64	...	...	...
	1959	3.47	...	...	...
	1960	2.48	...	...	...
	1961	3.00	...	...	...
	1962	2.61	...	...	...
	1963	4.88	...	...	...
	1964	4.55	...	...	...
	1958–64	3.52	...	...	...
	1960–64	3.50	...	...	...
Tall fescue and clover	1958	...	1.60	...	...
	1959	...	1.31	...	...
	1960	1.38	1.69	2.70	3.95
	1961	.41	1.05	1.73	3.42
	1962	2.53	2.65	2.76	2.84
	1963	.35	.66	1.42	3.08
	1964	1.81	2.50	4.07	5.36
	1958–64	...	1.64	...	...
	1960–64	1.30	1.71	2.54	3.73
Coastal bermudagrass and clover.	1958	...	2.84	...	...
	1959	...	2.05	...	...
	1960	1.92	2.96	4.04	7.88
	1961	1.55	2.18	2.55	3.71
	1962	2.39	3.18	4.11	5.83
	1963	1.22	2.66	3.94	6.69
	1964	2.15	4.15	5.94	6.67
	1958–64	...	2.86	...	...
	1960–64	1.85	3.03	4.12	6.16
Pensacola bahiagrass and clover.	1958	...	2.07	...	...
	1959	...	2.43	...	...
	1960	2.17	2.75	3.10	3.50
	1961	1.64	2.56	3.30	4.21
	1962	2.92	3.42	3.91	4.73
	1963	1.39	3.65	3.52	5.28
	1964	2.32	4.28	5.37	6.66
	1958–64	...	2.88	...	...
	1960–64	2.09	3.13	3.84	4.88

TABLE A–3.—*Corn yield by fertility level and cropping treatment after terminating the rotation*

Treatment No.	Cropping treatment	Consecutive years for corn	Year	Corn yield (bu/acre) at rate of nitrogen applied (lb/acre)			
				0	40	80	160
1	Corn continuously	11	1965	23.3	60.1	64.4	75.0
		12	1966	13.6	29.2	20.5	29.4
		13	1967	28.0	73.4	117.9	141.7
		14	1968	13.2	48.7	61.3	74.9
	Average			19.5	52.8	66.1	80.2
2	Corn after vetch	11	1965	83.3	84.0	82.4	79.0
		12	1966	24.9	25.8	24.8	27.2
		13	1967	45.8	105.6	130.7	139.2
		14	1968	35.2	68.7	75.9	66.8
	Average			47.3	71.0	78.4	78.0
3	Corn after rye	11	1965	44.5	76.7	76.0	82.0
		12	1966	20.1	22.3	24.2	27.9
		13	1967	39.7	89.6	117.5	132.1
		14	1968	21.6	58.2	61.5	69.2
	Average			31.5	61.7	69.8	77.8
7	Corn after 3 years of fescue	1	1965	66.0	87.6	100.3	98.0
		1	1966	34.8	28.3	28.5	29.1
		1	1967	123.7	149.8	146.7	143.0
	Average			74.9	88.6	91.8	90.0
	Corn after 3 years of fescue	2	1965	53.6	86.0	88.7	85.9
		2	1966	41.5	33.5	36.0	39.6
		2	1967	108.6	136.7	148.6	139.2
		2	1968	76.5	85.2	88.8	91.9
	Average			70.0	85.5	90.5	89.2
	Corn after 3 years of fescue	3	1966	39.5	32.3	28.7	41.3
		3	1967	73.9	117.0	146.5	143.9
		3	1968	60.7	90.1	96.6	95.3
	Average			58.0	79.8	90.6	93.5
	Corn after 3 years of fescue	4	1967	57.9	109.1	147.9	146.5
		4	1968	40.6	73.3	97.7	83.3
	Average			49.2	91.2	122.8	114.9
	Corn after 3 years of fescue	5	1968	43.0	77.1	79.9	87.3
8	Corn after 3 years of coastal bermudagrass.	1	1965	85.6	89.6	85.5	82.6
		1	1966	32.9	26.2	26.1	30.1
		1	1967	136.1	136.4	146.5	145.3
	Average			84.9	84.1	86.0	86.0
	Corn after 3 years of coastal bermudagrass.	2	1965	92.0	89.6	83.3	86.0
		2	1966	42.3	33.8	20.4	22.0
		2	1967	90.5	138.2	146.1	142.6
		2	1968	79.9	87.3	87.1	96.2
	Average			76.2	87.2	84.2	86.7
	Corn after 3 years of coastal bermudagrass.	3	1966	41.5	39.7	34.0	25.6
		3	1967	70.5	120.6	146.9	144.5
		3	1968	74.8	86.3	85.5	95.1
	Average			62.3	82.2	88.8	88.4
	Corn after 3 years of coastal bermudagrass.	4	1967	68.1	123.1	152.1	141.2
		4	1968	50.0	80.6	79.4	89.2
	Average			59.0	101.8	115.8	115.2
	Corn after 3 years of coastal bermudagrass.	5	1968	50.2	82.7	88.4	87.5

TABLE A–4.—*Yield of corn following four forage crops grown for 10 consecutive years with four rates of nitrogen fertilizer applied to the forages and zero nitrogen to the corn*

Forage crop	Year	Years of corn	Replication	Corn yield (bu/acre) at rate of nitrogen applied annually to forage[1] (lb/acre)			
				0	80	160	320
Tall fescue and crimson clover.	1965	1	1	61.0	80.1	83.3	80.8
	1965	1	2	75.4	77.0	69.6	76.2
	1966	2	1	30.2	33.0	41.5	50.9
	1966	2	2	45.3	45.7	44.8	45.2
	1967	3	1	51.4	59.9	66.3	64.3
	1967	3	2	63.0	76.6	79.2	79.3
	1968	4	1	35.3	75.9	85.5	96.6
	1968	4	2	50.7	78.1	74.1	77.7
Average				51.5	65.8	68.0	72.6
Coastal bermudagrass and clover.	1965	1	1	68.9	67.8	69.1	74.3
	1965	1	2	76.6	73.6	79.1	86.0
	1966	2	1	32.8	41.0	30.7	36.5
	1966	2	2	39.5	37.9	37.7	43.3
	1967	3	1	51.6	55.5	55.1	64.2
	1967	3	2	70.9	74.4	70.7	70.3
	1968	4	1	38.0	48.1	42.6	38.8
	1968	4	2	46.9	56.7	55.0	50.0
Average				53.1	56.9	55.0	58.0
Pensacola bahiagrass and clover.	1965	1	1	70.6	69.8	83.8	91.5
	1965	1	2	75.9	77.1	99.7	90.2
	1966	2	1	47.1	45.6	51.0	45.8
	1966	2	2	41.9	37.7	57.3	49.6
	1967	3	1	65.0	73.8	91.0	98.1
	1967	3	2	74.3	68.1	77.9	76.9
	1968	4	1	58.0	49.0	55.7	68.5
	1968	4	2	42.0	40.4	44.8	55.4
Average				59.3	57.7	70.2	72.0
Alfalfa	1965	1	1	93.0	...	...	...
	1965	1	2	90.5	...	...	...
	1966	2	1	55.4	...	...	...
	1966	2	2	46.8	...	...	...
	1967	3	1	98.8	...	...	...
	1967	3	2	93.0	...	...	...
	1968	4	1	65.9	...	...	...
	1968	4	2	59.9	...	...	...
Average				75.4	...	...	...

[1] 80 lb N/acre applied to grasses and 0 lb N/acre applied to alfalfa 1955–64; 0, 160, and 320 lb N/acre also applied to grasses 1960–64.

TABLE A–5.—*Rainfall, runoff, and soil loss by years with different cropping treatments*

Cropping treatment	Land slope (%)	Year	Rainfall		Runoff (in)		Soil loss (tons/acre)	
			Inches	Erosion index	With slope	Across slope	With slope	Across slope
Fallow soil, cultivated with no vegetative cover	7	1961	61.10	579	20.60	...	97.60	...
		1962	49.68	412	16.96	...	60.01	...
		1963	62.11	374	17.18	...	41.08	...
		1964	72.34	579	30.30	...	93.97	...
		1965	35.48	177	7.54	...	20.33	...
		1966	53.34	238	16.62	...	49.02	...
		1967	55.95	306	19.27	...	61.00	...
Average			55.71	381	18.35	...	60.43	...
Cotton continuously	7	1961	(1)	(1)	14.60	10.30	49.00	20.40
		1962	(1)	(1)	9.25	5.21	30.08	19.80
		1963	(1)	(1)	7.82	4.46	6.75	4.27
		1964	(1)	(1)	14.48	8.84	25.01	15.81
		1965	(1)	(1)	2.71	1.75	3.05	1.32
		1966	(1)	(1)	8.29	5.04	17.46	14.60
		1967	(1)	(1)	11.74	8.73	21.70	9.77
Average			(1)	(1)	9.84	6.33	21.86	12.88
Corn continuously	3	1961	(1)	(1)	5.00	...	0.50	...
		1962	(1)	(1)	8.42	...	3.49	...
		1963	(1)	(1)	9.31	...	2.82	...
		1964	(1)	(1)	10.26	...	2.37	...
		1965	(1)	(1)	1.68	...	.68	...
		1966	(1)	(1)	6.18	...	3.71	...
		1967	(1)	(1)	4.95	...	3.26	...
Average			(1)	(1)	6.54	...	2.40	...
Corn continuously	7	1961	(1)	(1)	12.00	11.20	26.70	11.80
		1962	(1)	(1)	8.01	5.82	20.68	7.89
		1963	(1)	(1)	8.24	3.28	6.07	2.36
		1964	(1)	(1)	8.02	7.30	8.06	2.64
		1965	(1)	(1)	2.22	.24	1.32	.14
		1966	(1)	(1)	4.69	2.64	11.26	2.31
		1967	(1)	(1)	6.01	1.27	10.66	1.01
Average			(1)	(1)	7.03	4.54	12.11	4.02
Corn continuously	11	1961	(1)	(1)	11.50	...	59.60	...
		1962	(1)	(1)	7.68	...	39.54	...
		1963	(1)	(1)	5.78	...	5.59	...
		1964	(1)	(1)	7.90	...	15.12	...
		1965	(1)	(1)	1.11	...	1.81	...
		1966	(1)	(1)	2.79	...	12.41	...
		1967	(1)	(1)	4.00	...	12.24	...
Average			(1)	(1)	5.82	...	20.90	...
3-year rotation of: (1) Coastal bermudagrass and crimson clover after corn	7	1962	49.48	412	6.78	8.72	11.00	13.02
		1963	62.11	374	2.37	1.80	.60	.20
		1964	72.34	579	4.14	2.48	.24	.26
		1965	35.48	177	.04	.09	.04	.06
		1966	53.34	238	.91	.21	.02	0
		1967	55.95	306	.26	.17	.04	0
Average			54.78	411	2.42	2.25	1.99	2.26

See footnotes at end of table.

TABLE A–5.—*Rainfall, runoff, and soil loss by years with different cropping treatments*—Continued

Cropping treatment	Land slope (%)	Year	Rainfall		Runoff (in)		Soil loss (tons/acre)	
			Inches	Erosion index	With slope	Across slope	With slope	Across slope
3-year rotation of:								
(2) Coastal bermudagrass and crimson clover second year	7	1962	(2)	(2)	3.36	4.17	0.23	0.33
		1963	(2)	(2)	1.48	4.48	.34	.49
		1964	(2)	(2)	4.54	3.12	.18	.08
		1965	(2)	(2)	.04	.05	0	0
		1966	(2)	(2)	1.03	4.53	.12	.21
		1967	(2)	(2)	.20	.10	.06	0
Average			(2)	(2)	1.78	2.74	0.16	0.19
(3) Corn after bermudagrass and crimson clover	7	1962	(2)	(2)	7.38	5.18	13.84	3.28
		1963	(2)	(2)	4.38	1.31	1.59	.72
		1964	(2)	(2)	7.18	8.94	3.52	1.18
		1965	(2)	(2)	.77	.07	.15	0
		1966	(2)	(2)	3.46	1.24	4.29	.80
		1967	(2)	(2)	3.36	1.17	3.16	.49
Average			(2)	(2)	4.42	2.99	4.43	1.08
(4) 3-year rotation average			54.78	411	2.87	2.66	2.19	1.17
3-year rotation of:								
(1) Tall fescue and crimson clover after corn	7	1961	62.10	579	...	1.00	...	0.30
		1962	50.70	412	...	.62	...	0
		1963	62.52	374	...	4.60	...	.44
		1964	73.48	579	...	20.79	...	3.66
		1965	34.87	177	...	.10	...	0
Average			56.73	424	...	5.42	...	0.88
(2) Tall fescue and crimson clover second year	7	1961	(3)	(3)	...	1.50	...	0.20
		1962	(3)	(3)	...	.25	...	0
		1963	(3)	(3)	...	1.32	...	0
		1964	(3)	(3)	...	10.16	...	.26
		1965	(3)	(3)	...	.75	...	0
Average			(3)	(3)	...	2.80	...	0.09
(3) Corn after 2 years of tall fescue and clover	7	1961	(3)	(3)	...	5.10	...	1.20
		1962	(3)	(3)	...	3.77	...	4.99
		1963	(3)	(3)	...	5.60	...	2.27
		1964	(3)	(3)	...	8.07	...	1.28
		1965	(3)	(3)	...	.24	...	.10
Average			(3)	(3)	...	4.56	...	1.97
(4) 3-year rotation average			56.73	424	...	4.26	...	0.98
4-year rotation of:								
(1) Tall fescue and crimson clover after cotton	7	1961	62.10	579	...	21.80	...	6.10
		1962	52.33	412	...	4.90	...	.32
		1963	64.00	374	...	7.60	...	3.22
		1964	74.48	579	...	19.77	...	10.34
		1965	34.87	177	...	1.15	...	.29
Average			57.56	424	...	11.04	...	4.05

See footnotes at end of table.

TABLE A–5.—*Rainfall, runoff, and soil loss by years with different cropping treatments*—Continued

Cropping treatment	Land slope (%)	Year	Rainfall		Runoff (in)		Soil loss (tons/acre)	
			Inches	Erosion index	With slope	Across slope	With slope	Across slope
4-year rotation of:								
(2) Tall fescue and crimson clover second year	7	1961	(4)	(4)	...	3.10	...	0.10
		1962	(4)	(4)	...	8.53	...	0
		1963	(4)	(4)	...	2.83	...	0
		1964	(4)	(4)	...	10.56	...	.14
		1965	(4)	(4)	...	.21	...	0
Average			(4)	(4)	...	5.07	...	0.05
(3) Corn after tall fescue and crimson clover	7	1961	(4)	(4)	...	9.80	...	4.30
		1962	(4)	(4)	...	4.54	...	5.83
		1963	(4)	(4)	...	9.20	...	3.38
		1964	(4)	(4)	...	6.42	...	1.02
		1965	(4)	(4)	...	.24	...	.10
Average			(4)	(4)	...	6.04	...	2.93
(4) Cotton after corn	7	1961	(4)	(4)	...	8.70	...	6.20
		1962	(4)	(4)	...	5.33	...	11.70
		1963	(4)	(4)	...	7.22	...	3.74
		1964	(4)	(4)	...	14.68	...	9.50
		1965	(4)	(4)	...	.23	...	.12
Average			(4)	(4)	...	7.23	...	6.25
(5) 4-year rotation average			57.56	424	...	7.34	...	3.32

[1] Same as for fallow treatment.
[2] Same as (1) above in 3-year rotation of coastal bermudagrass.
[3] Same as (1) above in 3-year rotation of tall fescue.
[4] Same as (1) above in 4-year rotation of tall fescue.

TABLE A–6.—*Yields of bermudagrass and crimson clover by years with 10 rates of nitrogen, phosphorus, and potassium*

[Tons per acre]

N–P_2O_5–K_2O (lb/acre)	Year	Common bermudagrass				Coastal bermudagrass			
		Grass only (no clover seeded)	Crimson clover	Grass only (clover seeded)	Grass & clover	Grass only (no clover seeded)	Crimson clover	Grass only (clover seeded)	Grass & clover
0–0–0	1955	1.32	1.53	1.76	3.29	2.30	1.41	2.74	4.15
	1956	.76	1.42	1.37	2.79	1.05	1.01	1.68	2.69
	1957	.62	1.42	.96	2.38	.97	1.24	1.78	3.02
Average		0.90	1.46	1.36	2.82	1.44	1.22	2.07	3.29
0–100–100	1955	1.44	1.47	1.85	3.32	2.60	1.48	3.39	4.87
	1956	1.17	1.80	1.38	3.18	1.25	1.31	1.86	3.17
	1957	.86	1.73	.98	2.71	1.09	1.98	2.08	4.06
Average		1.16	1.67	1.40	3.07	1.65	1.59	2.44	4.03
50–0–0	1955	1.79	1.53	1.73	3.26	3.10	1.46	3.22	4.68
	1956	1.55	1.37	1.93	3.30	2.29	.93	3.04	3.97
	1957	1.27	1.15	1.56	2.71	2.24	1.09	2.84	3.93
Average		1.54	1.35	1.74	3.09	2.54	1.16	3.03	4.19
50–50–50	1955	1.88	1.41	2.43	3.84	3.70	1.57	4.15	5.72
	1956	1.51	1.79	2.05	3.84	2.75	1.57	3.15	4.72
	1957	1.19	1.44	1.48	2.92	2.62	1.53	2.95	4.48
Average		1.53	1.55	1.99	3.53	3.02	1.56	3.42	4.97
100–50–50	1955	2.30	1.52	2.66	4.18	4.32	1.44	4.14	5.58
	1956	2.44	1.97	2.91	4.88	3.65	1.41	4.18	5.59
	1957	2.06	1.18	2.46	3.64	3.68	1.45	4.38	5.83
Average		2.27	1.56	2.68	4.23	3.88	1.43	4.23	5.67
200–50–50	1955	3.07	1.58	3.17	4.75	5.84	1.51	4.84	6.35
	1956	3.58	1.79	3.75	5.54	5.69	1.32	5.08	6.40
	1957	3.38	.95	3.34	4.29	5.92	1.06	5.34	6.40
Average		3.34	1.44	3.42	4.86	5.82	1.30	5.09	6.38
200–100–100	1955	3.37	1.40	3.31	4.71	5.34	1.44	5.51	6.95
	1956	4.02	1.84	3.98	5.82	5.61	1.35	5.74	7.09
	1957	3.84	1.12	3.60	4.72	5.97	1.41	6.15	7.56
Average		3.74	1.45	3.63	5.08	5.64	1.40	5.80	7.20
400–0–0	1955	3.49	1.54	2.91	4.45	5.78	1.45	5.24	6.69
	1956	3.84	1.07	3.39	4.46	5.36	.32	4.90	5.22
	1957	3.08	.39	2.59	2.98	5.07	.23	4.21	4.44
Average		3.47	1.00	2.96	3.96	5.40	0.67	4.78	5.45
400–100–100	1955	3.89	1.44	3.24	4.68	6.29	1.50	6.06	7.56
	1956	5.07	1.51	4.38	5.89	6.97	1.18	6.42	7.60
	1957	5.05	.59	4.32	4.91	7.61	.74	7.03	7.77
Average		4.67	1.18	3.98	5.16	6.96	1.14	6.50	7.64
400–200–200	1955	4.20	1.48	3.81	5.29	6.72	1.43	7.14	8.57
	1956	5.02	1.13	4.86	5.99	7.58	.86	7.53	8.39
	1957	5.34	.69	4.53	5.22	8.19	.75	7.84	8.59
Average		4.85	1.10	4.40	5.50	7.50	1.01	7.50	8.52

TABLE A–7.—*Yields of crimson clover and coastal bermudagrass by years with different levels of nitrogen, phosphorus, and potassium*

[Tons per acre]

$N–P_2O_5–K_2O$ (lb/acre)	Crimson clover				Coastal bermudagrass			
	1955	1956	1957	Average	1955	1956	1957	Average
0–0–0	1.14	0.51	1.39	1.01	2.77	1.58	1.60	1.98
0–0–50	1.19	.80	1.60	1.20	3.03	1.61	1.76	2.13
0–0–100	1.27	.84	1.59	1.23	3.29	1.75	1.54	2.19
0–0–200	1.12	.69	1.71	1.17	2.65	1.47	1.80	1.97
0–50–0	1.28	.38	1.59	1.08	3.46	1.59	2.09	2.38
0–100–0	1.36	.38	1.60	1.11	2.95	1.61	2.00	2.19
0–200–0	1.05	.27	1.64	.99	2.42	1.90	2.34	2.22
0–50–50	1.35	.92	1.62	1.30	3.25	1.62	1.87	2.25
0–50–100	1.37	.60	2.17	1.38	2.79	1.57	1.96	2.11
0–50–200	1.53	.80	2.10	1.48	3.53	2.17	2.09	2.60
0–100–50	1.37	.85	1.98	1.40	3.75	1.76	2.18	2.56
0–100–100	1.30	.60	1.94	1.28	2.94	1.67	2.06	2.22
0–100–200	1.44	.66	2.04	1.38	3.37	1.89	2.13	2.46
0–200–50	1.17	.29	1.84	1.10	2.92	1.97	2.47	2.45
0–200–100	1.26	.32	1.80	1.13	4.29	2.10	2.43	2.94
0–200–200	1.39	.37	1.90	1.22	3.32	1.84	2.28	2.48
100–0–0	1.29	.47	1.12	.96	4.46	3.63	3.58	3.89
100–0–50	1.34	.83	1.15	1.11	4.69	3.43	3.61	3.91
100–0–100	1.19	.87	1.11	1.06	3.75	3.62	3.62	3.66
100–0–200	1.32	.65	1.26	1.08	4.77	3.96	3.47	4.07
100–50–0	1.40	.33	1.14	.96	4.77	4.04	4.23	4.35
100–100–0	1.18	.20	.95	.78	4.43	3.97	4.01	4.14
100–200–0	1.36	.03	.74	.71	4.74	3.99	4.05	4.26
100–50–50	1.50	.92	1.54	1.32	5.30	4.40	4.06	4.59
100–50–100	1.53	.97	1.76	1.42	4.80	4.25	4.38	4.48
100–50–200	1.56	1.16	1.61	1.44	4.93	4.37	4.35	4.55
100–100–50	1.43	.90	1.43	1.25	4.88	4.12	4.07	4.36
100–100–100	1.50	.77	2.14	1.47	4.89	4.52	4.26	4.56
100–100–200	1.40	.65	2.13	1.39	4.68	4.07	4.28	4.35
100–200–50	1.54	.62	1.83	1.33	5.39	4.38	4.36	4.71
100–200–100	1.29	.52	1.72	1.18	5.17	4.54	4.79	4.83
100–200–200	1.54	.51	1.97	1.34	5.48	4.50	4.57	4.85
200–0–0	1.08	.40	.69	.72	4.69	4.36	4.16	4.40
200–0–50	1.21	.80	.72	.91	5.38	4.72	4.62	4.91
200–0–100	1.24	.87	.82	.98	5.47	5.09	4.74	5.10
200–0–200	1.07	.61	.77	.82	5.49	5.24	4.95	5.23
200–50–0	1.41	.42	.88	.90	5.33	4.94	4.74	5.00
200–100–0	1.36	.21	.81	.79	4.84	4.71	4.76	4.77
200–200–0	1.23	.01	.41	.55	5.73	5.11	4.68	5.17
200–50–50	1.44	.75	1.38	1.19	5.91	5.65	5.36	5.64
200–50–100	1.38	.91	1.12	1.14	5.90	5.66	5.48	5.68
200–50–200	1.38	1.02	1.51	1.30	5.73	5.55	5.51	5.60
200–100–50	1.26	.57	1.50	1.11	6.21	5.32	5.54	5.69
200–100–100	1.28	.73	1.40	1.14	6.16	5.55	5.68	5.80
200–100–200	1.26	.84	1.69	1.26	5.92	6.33	5.97	6.07
200–200–50	1.15	.31	1.37	.94	5.41	5.39	5.70	5.50
200–200–100	1.36	.30	1.21	.96	5.98	5.54	6.03	5.85
200–200–200	1.35	.40	1.65	1.13	6.53	6.41	6.37	6.44
400–0–0	1.11	.21	.32	.55	5.30	4.17	3.82	4.43
400–0–50	1.34	.58	.41	.78	5.99	5.22	4.73	5.31
400–0–100	1.29	.64	.55	.83	4.99	5.20	5.28	5.16
400–0–200	1.31	.71	.50	.84	6.05	5.92	5.66	5.88

TABLE A–7.—*Yields of crimson clover and coastal bermudagrass by years with different levels of nitrogen, phosphorus, and potassium*—Continued

[Tons per acre]

$N–P_2O_5–K_2O$ (lb/acre)	Crimson clover				Coastal bermudagrass			
	1955	1956	1957	Average	1955	1956	1957	Average
400–50–0	1.22	.12	.34	.56	5.48	5.12	4.25	4.95
400–100–0	1.41	.14	.31	.62	5.49	5.16	5.00	5.22
400–200–0	1.27	.00	.22	.50	6.05	5.75	5.19	5.66
400–50–50	1.40	.82	.80	1.01	6.48	6.14	6.18	6.27
400–50–100	1.42	.84	.79	1.02	6.40	6.39	6.65	6.48
400–50–200	1.41	.71	1.05	1.06	6.10	6.61	6.93	6.55
400–100–50	1.50	.51	.67	.89	6.52	6.11	6.18	6.27
400–100–100	1.29	.64	.91	.95	6.10	6.42	6.52	6.35
400–100–200	1.41	.66	1.09	1.05	6.10	7.01	7.05	6.72
400–200–50	1.28	.29	.74	.77	6.35	6.42	5.97	6.25
400–200–100	1.38	.23	.84	.82	6.87	7.09	7.37	7.11
400–200–200	1.41	.51	1.21	1.04	6.93	7.49	7.54	7.32

*1977-GPO-1750-S/771-040/23

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